PHOENIX LAKE IRWM RETROFIT

Attachment 7 - Economic Analysis: Flood Damage Reduction Costs and Benefits

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1.0 Description of the Flood Damage Reduction Project and Its Relationship to Other Projects

The Flood Damage Reduction Project component of the Phoenix Lake IRWM Retrofit consists of seismic upgrade of the dam to enable storage of floodwater to a higher water level (el. 180 ft); erosion protection of the dam face to enable rapid drawdown by preventing sloughing of dam face and raising of the dam crest by at least 1.1 ft to enable storage to a higher water level for peak flow attenuation and flood reduction; modification of the intake/outlet works of the low-level drain pipeline to enable rapid lake drawdown in advance of a forecasted flood to provide additional storage and floodwater attenuation; and, excavation of the lake bottom to prevent entrainment and discharge of sediment as well as to provide an adequate refugia pool for fish and other aquatic wildlife when the lake is fully drawn down. Without the Flood Damage Reduction Project component, the lower reach of Corte Madera Creek will be limited to about the 4-percent-annual chance level of flood protection. Public safety and property downstream of the Ross Creek confluence in the communities of Ross, Kentfield, Larkspur and Greenbrae will remain at this unacceptably higher risk of flooding.

The goal of the Flood Damage Reduction Project is to enable Phoenix Lake to function as a flood detention basin. The objective of flood detention operations is to attenuate flows produced in the upper Ross Creek watershed sufficiently to reduce the peak discharge to lower Ross Creek, and hence lower Corte Madera Creek, during the 1-percent-chance-annual flood by about 650 cfs[1]. In order to achieve this objective, Phoenix Lake needs to provide about 460 acre-feet of flood storage capacity[2] for floodwater attenuation. Accordingly, flood detention operations call for rapid drawdown of the lake level ahead of a forecasted heavy storm event in two steps to elevation 140 ft and storage of floodwaters up to elevation 180 ft.

These flood detention operations require improvements and modifications to the dam, spillway, reservoir and inlet/outlet works. The earthen embankment dam needs structural strengthening to improve seismic stability at the higher water level, elevation 180 ft; the dam face needs erosion protection to enable rapid drawdown by preventing sloughing of dam face; the dam crest needs to be raised by at least 1.1 ft to provide adequate freeboard for the spillway to pass the DSOD-developed 30,000-year design flood; the intake/outlet works of the low-level drain pipeline need modification to enable rapid lake drawdown in advance of a forecasted flood; and, the lake bottom needs to be excavated to provide adequate dead pool refugia for fish and other aquatic wildlife and to prevent entrainment and discharge of sediment when the lake is fully drawn down to el. 140 ft.[3]

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[1] Phoenix Lake can also reduce peak flows for smaller floods. The amounts of peak flow reduction at the Ross streamflow gage for the 50-year, 25-year, 10-year, and 5-year floods are estimated to be approximately 600 cfs, 510 cfs, 370 cfs, and 270 cfs, respectively.

[2] Including the storage of about 410 acre-ft between elevations 140 ft and 180 ft and a surcharge storage of about 50 acre-ft).

[3] In addition, the spillway crest, currently at el. 174 ft, needs to be raised six feet to el. 180 ft for the added storage and attenuation capacity. However, the added storage and attenuation capacity is an *enhancement*

The Flood Damage Reduction Project has four elements that address the above-described needs: (1) dam seismic upgrade element, (2) dam face erosion protection and dam crest raising element, (3) low-level drain pipeline intake element, and (4) lake bottom excavation element. These elements work synergistically with other component projects of the Phoenix Lake IRWM Retrofit to enhance their benefits, as summarized in Table 1.

Table 1 Relationship of the Flood Damage Reduction Project Elements to Other Projects of the Phoenix Lake IRWM Retrofit

Flood Damage Reduction Project Element	Relationship to Other Projects				
	Water Supply	Water Quality	Ecosystem Restoration	Recreation /Public Access	Explanation
Dam Seismic Upgrade	X			X	Enhances water supply by enabling increased storage and lake yield; adds to lake's recreational value by expanding lake area thereby improving the aesthetic appeal, and enlarging the lake coldwater habitat volume thereby improving the trout fishery.
Dam Face Erosion Protection and Raising	X				Enhances water supply by providing necessary freeboard for storage to a higher water level (raising) thereby increasing lake yield.
Low-Level Drain Pipe Intake		X	X		Enhances ecosystem restoration and improves downstream water quality by enabling withdrawal of deep, cool water for downstream release thereby improving fresh coldwater beneficial use.
Lake Bottom Excavation	X				Enhances water supply by providing adequate dead pool storage during water supply drawdown.

Phoenix Lake operations for flood damage reduction will be coordinated with operations for water supply, water quality, ecosystem restoration, and public recreation. A coordinated operations plan (COP), establishing rules and criteria for operating Phoenix Lake in a manner that achieves the lake's new multi-use benefits, will be developed that is mutually acceptable to MMWD and FZ9.

A preliminary COP is described in Appendix 2 of Attachment 3, Work Plan. Under the preliminary COP, operations would follow a general "rule curve" which defines normal operating water levels during the wet (flood) season and the dry (water supply) season. The COP also defines criteria for drawdown and refilling during the wet-dry transitional period.

to the flood reduction project; while it is *essential* to the water supply project. For this reason, the element of raising the spillway crest is included in the water supply project and, accordingly, is described in **Attachment 8 (Economic Analysis: Water Supply Costs and Benefits)**.

2.0 Description of the Flood Damage Reduction Project's Economic Costs

Economic costs associated with the Flood Damage Reduction Project include initial capital costs of its facility elements and future operations and maintenance costs. Initial capital costs are detailed in Attachment 4, Budget. These initial capital costs cover all costs associated with initial project implementation including a) direct project administration, b) land purchase and easement, c) planning, design, engineering, and environmental documentation, d) construction and implementation, e) environmental compliance, mitigation, and enhancement, f) construction administration, g) other costs, and h) construction and implementation contingency (25%).

Future operations and maintenance costs are recurring costs that are incurred over the life of the Flood Damage Reduction Project elements. Annual costs include administration, operation, maintenance, replacement and repairs, and others such as monitoring and inspections and reporting. Annual costs are estimated as a percentage (1%) of the construction cost[4].

Table 2 shows the cost details of the initial capital costs and future operations and maintenance costs. Capital costs for the Flood Damage Reduction Project amount to about $12,177,000 (2009 dollars). The capital costs will be incurred in 2011 through 2015 and distributed according to the schedule of Attachment 5. Capital costs that were already expended in the past are considered sunk costs and are not included in this analysis. The incremental costs associated with project administration, operation, maintenance, replacement, and others (i.e., wet season lake level and tributary inflow data collection) amount to a total of about $4,090,000 (non-discounted 2009 dollars) over the useful lifetime of the project (assumed 50 years).

Together, the present value capital and O&M costs for the Flood Damage Reduction Project at 6% discount rate amount to about $9,633,000 through 2065.

[4] Refer to the construction cost estimation table in section 3.1.2 of Attachment 3, Work Plan. The 1% was applied to the construction cost excluding the cost for general requirements.

Table 2 Annual Cost of Flood Damage Reduction Project (in 2009 Dollars)
Project: Phoenix Lake IRWM Retrofit Project – Flood Damage Reduction Project

	Initial Costs	Operation and Maintenance Costs [1]							
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Year	Grand Total Costs	Admin	Operation	Maintenance	Replacement	Other	Total Costs (a) +…+ (f)	Discount Factor [2]	Discounted Costs (g) × (h)
2009								1.000	
2010								0.943	
2011	$365,000						$365,000	0.890	$324,850
2012	$274,000						$274,000	0.840	$230,160
2013	$253,000						$253,000	0.792	$200,376
2014	$281,000						$281,000	0.747	$209,907
2015	$11,005,000						$11,005,000	0.705	$7,758,525
2016		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.665	$54,397
2017		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.627	$51,289
2018		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.592	$48,426
2019		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.558	$45,644
2020		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.527	$43,109
2021		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.497	$40,655
2022		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.469	$38,364
2023		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.442	$36,156
2024		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.417	$34,111
2025		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.394	$32,229
2026		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.371	$30,348
2027		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.350	$28,630
2028		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.331	$27,076
2029		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.312	$25,522
2030		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.294	$24,049
2031		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.278	$22,740
2032		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.262	$21,432
2033		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.247	$20,205
2034		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.233	$19,059
2035		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.220	$17,996
2036		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.207	$16,933
2037		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.196	$16,033
2038		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.185	$15,133
2039		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.174	$14,233
2040		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.164	$13,415
2041		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.155	$12,679
2042		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.146	$11,943
2043		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.138	$11,288
2044		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.130	$10,634
2045		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.123	$10,061
2046		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.116	$9,489
2047		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.109	$8,916
2048		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.103	$8,425
2049		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.097	$7,935
2050		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.092	$7,526
2051		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.087	$7,117
2052		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.082	$6,708
2053		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.077	$6,299
2054		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.073	$5,971
2055		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.069	$5,644
2056		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.065	$5,317
2057		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.061	$4,990
2058		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.058	$4,744
2059		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.054	$4,417
2060		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.051	$4,172
2061		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.048	$3,926
2062		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.046	$3,763
2063		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.043	$3,517
2064		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.041	$3,354
2065		$19,200	$19,200	$19,200	$19,200	$5,000	$81,800	0.038	$3,108
Project Life	$12,177,000	$960,000	$960,000	$960,000	$960,000	$250,000	$16,268,000		
								Total Present Value of Discounted Costs (Sum of Column (i))	**$9,633,000**

(1) The incremental change in O&M costs attributable to the project; (2) 6% discount rate.

3.0 Description of the Project's Expected Flood Damage Reduction Benefits

3.1 Estimates of Historical Flood Damage Data

Floods in Ross Valley have occurred with varying degrees of severity. Prior to establishment in 1951 of the USGS streamflow gaging station on Corte Madera Creek in Ross, flooding was reported in 1914, 1925, 1937, and 1942. Since the gage in Ross has been in operation, flood flows have been recorded in calendar years 1951, 1955, 1958, 1967, 1969, 1970, 1982, 1983, 1986, 1994, and 2005. Of these, the two most severe floods occurred in 1982 and 2005, with peak discharges of approximately 7,200 cfs and 6,800 cfs; the percent-annual-chances of which were approximately 0.6 percent and 1 percent, respectively. Historical flooding has caused extensive property damage and economic hardship to residents, businesses, and local governments, and has threatened the lives of those living in the floodplain, with at least one recorded death occurring in the 1955 flood and at least one rescue of a stranded motorist reported by the Ross Valley Fire Department during the 2005 flood. The estimated physical damages (structure and contents) for the 1982 and 2005 floods were approximately 140 million and 120 million, respectively.

3.2 Description of Methods Used to Estimate Without- and With-Project Conditions

In this analysis, only structural and contents damages were estimated quantitatively. Appendix 1 of this attachment provides detailed information about the data, methods, and assumptions used in the analysis to quantify structural and contents damages.

The following steps were taken to conduct quantitative flood damage and benefits analysis for the without-Project and with-Project conditions:

- Modeling and mapping the flood extent and inundation depth for a range of recurrence/probability floods (i.e., 5-year, 10-year, 25-year, 50-year, 100-year, 250-year, and 500-year floods) under without-Project and with-Project conditions.
- Estimating flood damage for the range of flood events under without-Project and with-Project conditions and prevented event damage by the Project (i.e., event benefit). The event damage was estimated on a parcel-by-parcel basis using first finished floor elevations, square footages, and types of buildings and the floodplain mapping results. Buildings were classified into four categories based on the County Assessor's records: residential, commercial, industrial, and "tax exempt" (which includes schools and government buildings). The depth-damage functions for residential and non-residential buildings and contents developed by the U.S. Army Corps of Engineers were used in the flood damage analysis. The construction value of the building was estimated using a unit construction value of $200 per square foot for the Ross Valley. Content values were estimated using the DWR-recommended content-to-structure value ratios, which are typically approximately 50 percent for residential, 100% for commercial, 150% for industrial, and 100% for public buildings.
- Estimating expected annual damage (EAD) under without-Project and with-Project conditions and prevented EAD by the Project (i.e., EAD benefit).

The Stetson-developed and calibrated MIKE FLOOD unsteady flow hydraulic model for the Ross Valley was used to map the flood extent and inundation depth (refer to Appendix 1 of this attachment for descriptions of the MIKE FLOOD model).

3.3 Estimates of Existing Without- and With-Project Conditions

Following the methods described above, flood damages for the 5-year, 10-year, 25-year, 50-year, 100-year, 250-year, and 500-year flood recurrences/probabilities under without-Project and with-Project conditions were estimated and are given in Table 3 and shown in Figure 1.

Expected annual damage (EAD), also called the average annual damage, is the probability-weighted average of all possible annual damages (i.e., annual damages that could occur under the full range of flood recurrences/probabilities). As expected, the damage-probability function assigns a higher damage to the larger magnitude, rarer (i.e., low probability) floods and, conversely, assigns lower damage to the smaller magnitude, more frequent (i.e., higher probability) floods. Expected annual damage is the summation of all the possible products of probability times damage that are reflected in the damage-probability function, which is represented by the area below the respective curve shown in Figure 1. Expected annual damages and expected prevented annual damages for without-Project and with-Project conditions are given in Table 4. The expected prevented annual damage by the Project is estimated to be approximately $689,000. Table 4 also gives the estimated present value of future benefits, which is the expected prevented annual damage brought forward to a present worth at an assumed discount rate (i.e., 6%) over the Project lifetime (i.e., 50 years). The estimated present worth of future benefits of the Project is approximately $7,662,000.

Table 3 Event Damage under Without- and With-Project Conditions
(Project: Phoenix Lake IRWM Retrofit – Flood Damage Reduction Project)

Hydrologic Event	Event Probability	Without-Project			With-Project			Event Benefit ($)
		Damage to Building ($)	Damage to Contents ($)	Total Damage ($)	Damage to Building ($)	Damage to Contents ($)	Total Damage ($)	
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
				(c) + (d)			(f) + (g)	(e) – (h)
5-Year	0.200	$1,758,000	$1,728,000	**$3,485,000**	$1,519,000	$1,447,000	**$2,966,000**	**$519,000**
10-Year	0.100	$7,530,000	$6,218,000	**$13,749,000**	$4,560,000	$4,544,000	**$9,104,000**	**$4,645,000**
25-Year	0.040	$23,067,000	$25,127,000	**$48,194,000**	$20,197,000	$23,525,000	**$43,722,000**	**$4,472,000**
50-Year	0.020	$35,104,000	$40,318,000	**$75,422,000**	$33,525,000	$38,613,000	**$72,138,000**	**$3,284,000**
100-Year	0.010	$54,330,000	$64,778,000	**$119,108,000**	$51,261,000	$61,788,000	**$113,050,000**	**$6,058,000**
250-Year	0.004	$74,965,000	$89,308,000	**$164,272,000**	$73,526,000	$87,838,000	**$161,364,000**	**$2,909,000**
500-Year	0.002	$93,003,000	$112,833,000	**$205,836,000**	$90,865,000	$110,279,000	**$201,145,000**	**$4,691,000**

Figure 1 Flood Damage - Probability Curves

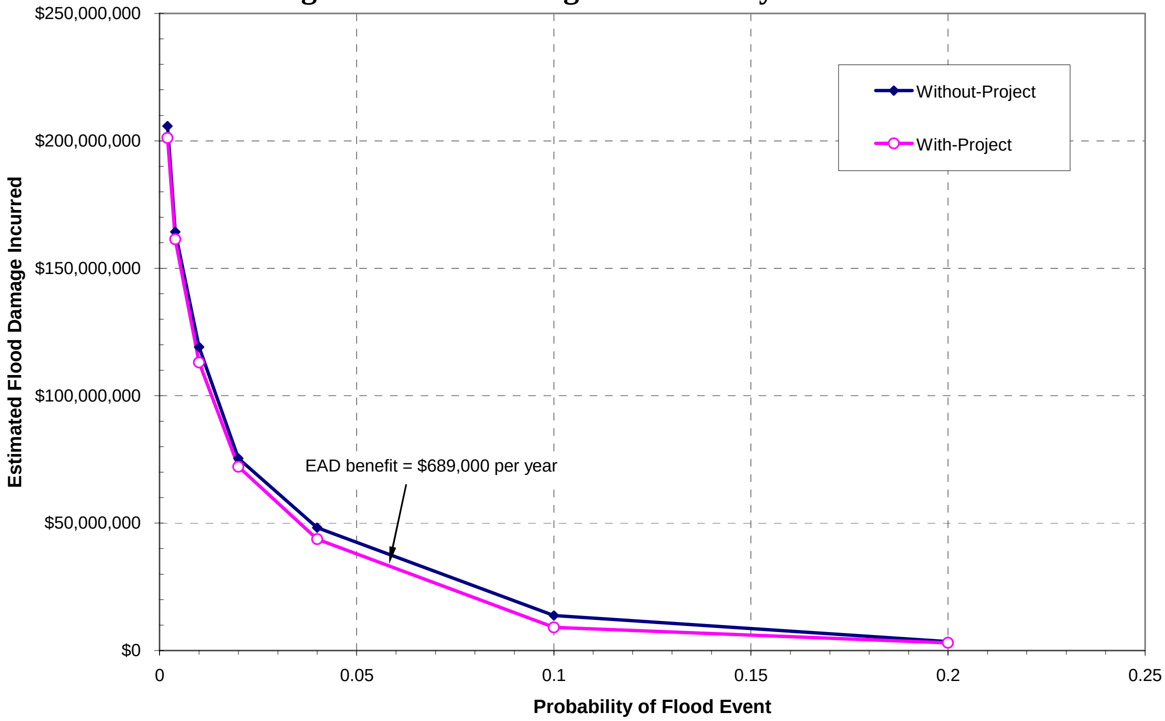

Table 4 Present Value of Expected Annual Damage Benefits (Project: Phoenix Lake IRWM Retrofit – Flood Damage Reduction Project)			
(a)	Expected Annual Damage Without Project (1)		$6,149,000
(b)	Expected Annual Damage With Project (1)		$5,460,000
(c)	Expected Annual Damage Benefit	(a) – (b)	$689,000
(d)	Present Value Coefficient (2)		11.12
(e)	**Present Value of Future Benefits (in 2009 dollars)**	**(c) × (d)**	**$7,662,000**

(1) This program assumes no population growth thus EAD will be constant over analysis period.
(2) 6% discount rate; 50-year analysis period from 2015 (base year) to 2065. The annual benefit will be realized starting in 2016.

3.4 Description of the Distribution of Local, Regional, and State-Wide Benefits and Identification of Beneficiaries

The Flood Damage Reduction Project will provide local benefits by providing improved flood protection to areas below Phoenix Lake along Ross Creek and lower Corte Madera Creek. The beneficiaries of improved flood protection are the residents, businesses, property owners, and public agencies in the Towns of Ross and Larkspur and unincorporated communities of Kentfield, Greenbrae.

The Flood Damage Reduction Project will provide regional benefits by avoiding impacts of flooding on businesses and public agencies that employ people from surrounding regions. Businesses and public agencies in the Towns of Ross and Larkspur and unincorporated communities of Kentfield, Greenbrae employ people from throughout the Bay Area. To the extent that flood protection is improved, flood damage is avoided, and businesses are able to keep people employed, the Flood Damage Reduction Project will provide regional benefit to the greater Bay Area region.

The Flood Damage Reduction Project can provide statewide benefits by reducing flood damage and thereby reducing the potential need to draw from State disaster relief funds, as occurred during the great floods of 1982 and 2005. The Statewide beneficiaries of reduced reliance on the State disaster relief funds are the other potential users of the funds.

3.5 When the Benefits Will Be Received

As described in Attachment 5 (Schedule), construction of the Flood Damage Reduction Project will be completed and fully online by the end of 2015. So, the prevented flood damage benefit by the Project will be received starting in 2016.

All facility components of the Flood Damage Reduction Project are assumed to have a useful project life of 50 years and, thus, benefits are calculated from the time the project comes online through 2065 (50 years after the project comes online).

3.7 Uncertainty of the Benefits

The benefits of the Flood Damage Reduction Project depend on future hydrologic conditions in the Phoenix Lake watershed, specifically flood conditions, which are always subject to a degree of uncertainty. Estimates of the frequency and probability of flooding over the long term were derived from analyses using standard hydrologic methods based on historical hydrological data. It is possible that climate change or some other unforeseen factor may cause future hydrologic conditions to significantly differ from the historical conditions that formed the basis of the estimates of the flood damage reduction benefits. However, that possibility cannot be quantified.

With respect to the precision of the hydrologic analyses that formed the basis of the estimates of the flood damage reduction benefits, “uncertainty” is a measure of imprecision of knowledge of parameters, data, and functions used to describe the hydrologic, hydraulic, and economic aspects of a flood damage reduction project plan. These parameters, data, and functions would result in some degree of uncertainty of the estimated benefit. Following is a list of main parameters, data, and functions that affect the estimated benefit:

1) Discharge-probability functions obtained from flood frequency analysis used as input in hydraulic modeling;
2) Imperfect channel geometry and floodplain topography used as input in hydraulic modeling;
3) Imperfect hydraulic modeling results for flood inundation extent and depth;
4) First finished floor elevations of buildings;
5) Depth-damage functions for structures and contents; and,
6) Structure value and contents value estimates.

However, the uncertainty associated with these parameters has not been quantified.

3.8 Description of Any Adverse Effects

Potential adverse effects of the Flood Damage Reduction Project are construction-related, such as effects of dewatering of the lake on aquatic wildlife and effects on public use of the lake during construction. Post-construction effects include effects of using Phoenix Lake for flood detention on lake levels and shoreline vegetation and habitat. These and any other potential adverse effects will be analyzed in the environmental documentation. Under CEQA, any potential adverse effects must be mitigated to a level of less than significant.

4.0 Seismic Benefits

4.1 Brief Summary of Geologic Hazards Evaluation

Phoenix Lake is located within the seismically active California Coast region and will therefore experience the effects of future earthquakes. Such earthquakes could occur on any of several active faults within the region. The California Geological Survey (CGS, 2000) has mapped various active and inactive faults in the region. Based on the CGS information, there are no known active faults passing through or in the immediate proximity of the property. The closest known active fault is the San Andreas Fault, which is located about 6.4 miles (10.3 kilometers) to the west.

Numerous earthquakes have occurred in the region within historical times. The results of our computer database search indicate that 70 earthquakes (Richter Magnitude 5.0 or larger) have occurred within 100 kilometers (62 miles) of the site between 1735 and 2010. Significant earthquakes to affect the project site are summarized in Table 5. The dam experienced the affects of the Great 1906 San Francisco Earthquake and remained intact with minor sloughing of the upstream face (see Appendix 4 of Attachment 3 (Work Plan)). The reservoir had not been filled at the time of the earthquake. As shown in Table 5, Great 1906 San Francisco Earthquake had a Richter magnitude of 8.2 with the epicenter about 29 kilometers (18 miles) away from Phoenix Lake. Fault rupture occurred through Marin County at a distance about 6.4 miles (10.3 kilometers) west of the dam.

Miller Pacific Engineering Group conducted geologic hazards evaluation of Phoenix Lake dam (see Appendix 4 of Attachment 3, Work Plan). The results showed that the factors of safety under pseudo-static (seismic) conditions are less than 1.0, indicating deformation of the dam will likely occur during strong seismic shaking. In the pseudo-static analysis, both deterministic and probabilistic seismic accelerations were evaluated. For the deterministic analysis, the seismic peak bedrock acceleration of the site due to a seismic event of the nearest San Andreas Fault (moment magnitude: 7.8; distance: 10 km from the site) is 0.53g for the 84th percentile. For the probabilistic analysis, predicted peak ground accelerations for the common recurrence intervals, 10% in 50 years (or 475-year return period) and 2% in 50 years (or 2,475-year return period), are 0.42g and 0.72g, respectively. The level of acceleration (0.53g) from the deterministic analysis corresponds with a roughly 8% in 50 years probability of exceedance or 600-year return period.

Table 5 Historical Significant Earthquake Activity in the Region of Phoenix Lake Dam
(Source: USGS (2010))

Epicenter (Latitude, Longitude)	Magnitude	Fault	Year	Distance
37.80, -122.20	6.8	Hayward	1836	37 km
37.60, -122.40	7.0	San Andreas	1838	42 km
37.70, -122.10	6.8	Hayward	1868	50 km
38.20, -122.40	6.2	Rodgers Creek	1898	31 km
		Post Construction		
37.70, -122.50	8.2	San Andreas	1906	29 km
37.67, -122.48	5.3	San Andreas	1957	32 km
38.46, -122.69	5.7	Hayward	1969	56 km
37.85, -121.82	5.8	San Gregorio	1980	67 km
37.91, -121.69	4.5	San Andreas	1999	10 km
37.43, -121.77	5.6	Calaveras	2007	91 km

4.2 Seismic Failure Damage Analysis

A seismic failure damage analysis was prepared for the Phoenix Lake dam for both without- and with-Project conditions. The analysis for without-Project conditions mainly included:

- Modifying the inundation extent of the existing Phoenix Lake dam failure inundation polygon originally from the State of California, Office of Emergency Services (1974);
- Calculating inundation depth based on the modified inundation extent; and,
- Estimating potential inundation damage.

Under with-Project conditions, the normal operating lake level will be raised by 6 ft (from elevation 174 ft to 180 ft) and the normal storage volume will be increased by about 40% (from current 300 acre-ft to 420 acre-ft). Assuming that a 40% increase in reservoir storage would translate to a 40% increase in discharge at the peak of the flood wave, the water surface elevation at each of selected cross sections was estimated by increasing the flow area at each cross section by 40%. This analysis also assumed that the flow velocity at each cross section is the same for both without- and with-Project conditions.

Appendix 2 of this attachment provides more detailed information about the data and methods used in the analysis. Table 6 shows the seismic failure economics data. As shown in Appendix 3 of this attachment, the estimated probability of seismic event causing the same displacement of 30”-100” is about 2% in 50 years and 0.2% in 50 years for without- and with-Project conditions, respectively. The magnitudes of these seismic events would be greater than 7.8, which has a probability of 8% in 50 years as discussed in section 4.1 above.

The potential inundation damages due to seismic failure for without- and with-Project conditions are estimated to be approximately $277 million and $762 million, respectively.

Table 6 Seismic Failure Economics Data

Variables	Without Project	With Project
Earthquake magnitude which causes structure failure	Greater than 7.8	Greater than 7.8
Estimated probability of seismic event causing structure failure	0.0004	0.00004
Potential inundation damage	$277,000,000	$762,000,000

5.0 Other Flood Damage Reduction Benefits

The economic benefit of the Flood Damage Reduction Project has been described and quantified above in terms of future reduced flood damage; that is, the dollar value of the flood damage that is reduced in the future over the long term. This dollar value of reduced flood damage was estimated based on avoided physical damage to buildings and contents only. It is important to point out that the Project would provide other additional flood damage reduction benefits which have not and cannot be quantified due to a lack of data needed for quantification. These benefits are economic and non-economic in nature and include, but are not limited to, the following benefit types:

- Avoided physical damage
  - Buildings
  - Contents
  - Infrastructure
  - Landscaping
  - Vehicles
  - Equipment
  - Nursery crops
  - Ecosystems
- Avoided loss of functions:
  - Loss of business income
  - Loss of rental income
  - Loss of wages
  - Loss of public services
  - Loss of utility services
  - Transportation system disruptions
- Avoided emergency response costs:
  - Evacuation and rescue costs
  - Security costs
  - Dewatering, debris removal and cleanup costs
  - Emergency flood management system repairs
  - Humanitarian assistance
- Avoided public safety and health impacts:
  - Population at risk
  - Casualties
  - Displacement/shelter needs
  - Critical facilities

The flood of December 31, 2005, an approximate 100-year event, provided many real world examples of the types of benefits described in the table above that the Project would provide. The flood caused significant damage to private residences, private property, businesses, schools and municipal infrastructure in the Towns of Fairfax, San Anselmo, Ross, and Larkspur and in the unincorporated communities of Kentfield and Greenbrae. Total property damage has been estimated at well over $100 million. Emergency crews expended considerable resources during and in the days after the flood event. Local governments spent millions of dollars in cleanup and repair of damaged public infrastructure. The business district of downtown San Anselmo was severely damaged. Many businesses shut down while repairs were made, and several businesses did not return in the towns of San Anselmo and Ross. Emergency bank repair in one location cost the Flood Control District over $100,000. This was necessary to prevent the undermining of a private residence. Some structures in the creek were permanently damaged. While repairs were being made, there were significant losses of income from businesses, rentals, and wages as well as losses in local tax revenues. Emergency contracts for repairs and overtime pay for public safety personnel and public works staff magnified the burden on local governments. The Town Halls, fire stations, and other municipal buildings in Fairfax and San Anselmo were severely damaged and had to be vacated for over a year while major repairs or total rebuilds were carried out. Floodwater depth at the San Anselmo firehouse was over 4 feet at the peak of the flood. Although during the recovery period these Towns set up temporary offices in trailers, public services were not at their full, pre-flood performance levels and capacities. The recovery period lasted for three years for some public services in the Towns of Fairfax and San Anselmo.

The people of Ross Valley have clearly demonstrated a willingness and desire to reduce the potential for more damage in the future by electing to assess themselves a flood fee with an average fee of $180 per parcel per year. The Phoenix Lake IRWM Retrofit project offers a golden opportunity for the county, the water district, and state government to partner with the people of Ross Valley to significantly reduce the risk of such flooding in the future.

APPENDIX 1 TO ATTACHMENT 7

FLOODPLAIN MAPPING AND ENGINEERING ECONOMIC ANALYSIS OF PHOENIX LAKE FLOOD DAMAGE REDUCTION PROJECT

Stetson Engineers Inc.
February 15, 2011

An engineering economic analysis was prepared for the Phoenix Lake Flood Damage Reduction Project (Project). The analysis mainly included:

- Modeling and mapping the flood extent and inundation depth for a range of flood events under without-Project and with-Project conditions;
- Estimating flood damage for the range of flood events under without-Project and with-Project conditions and prevented event damage by the Project (i.e., event benefit); and,
- Estimating expected annual damage (EAD) under without-Project and with-Project conditions and prevented EAD by the Project (i.e., EAD benefit).

The economic benefit of the Project can be expressed in terms of prevented flood damage, that is, the dollar value of the flood damage that is prevented by the Project over the long term (i.e., Project lifetime). The value of flood damage prevented was estimated by comparing the damage that would be expected to occur under without-Project conditions against the damage that would be expected to occur with the Project in place.

Floodplain Inundation Mapping under Without- and With-Project Conditions

The extent and depth of flood inundation are basic information required for flood damage analysis. The extent and depth of flood inundation under without-Project and with-Project conditions were estimated for a range of recurrence/probability floods and are summarized in Table 1.

Table 1 Summary of Flood Events That Were Simulated for Floodplain Inundation Mapping and Depth of Inundation

Condition	Flood Recurrence/Probability						
	5-yr/.2 prob.	10-yr/.1 prob.	25-yr/.04 prob.	50-yr/.02 prob.	100-yr/.01 prob.	250-yr/.004 prob.	500-yr/.002 prob.
Without-Project	X	X	X	X	X	X	X
With-Project	X	X	X	X	X	X	X

The extent and depth of flood inundation for the flood events summarized in Table 1 under without-Project and with-Project conditions were mapped based on simulations using the Stetson-developed MIKE FLOOD unsteady flow hydraulic model for the Ross Valley[1]. The MIKE FLOOD was developed and used for the Ross Valley Flood Reduction and Creek Management Master Plan study in 2010. So the MIKE FLOOD model domain (see Figure 1) covers the entire Ross Valley, including both the affected downstream by the Flood Damage Reduction Project of the Phoenix Lake IRWM Retrofit and the unaffected areas upstream of the Project.

ArcGIS was used to map the extent of floodplain inundation by intersecting the MIKE FLOOD-computed water surface DEM with the floodplain topographic surface DEM. Figures 2 through 8 show the floodplain inundation maps for the 5-year, 10-year, 25-year, 50-year, 100-year, 250-year, and 500-year recurrence/probability floods for without-Project and with-Project conditions.

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[1] MIKE FLOOD, developed by Danish Hydraulic Institute (DHI), is a specialized software package for analyzing water levels and flooding in an urban environment, river basin, and marine coastal area. It is one of the FEMA-approved models for the National Flood Insurance Program.

MIKE FLOOD integrates the MIKE 11 (one-dimensional model of river flow) and MIKE 21 (two-dimensional model of free-surface floodplain flow) models by linking MIKE 21 grid cells to a MIKE 11 river reach and dynamically solving the flow exchange between the two models. Using a coupled approach enables the best features of both one-dimensional and two-dimensional models to be utilized, while at the same time avoiding many of the limitations of resolution and accuracy often encountered when using a one-dimensional model or a two-dimensional model separately. Given the two-dimensional flow pattern in the Ross Valley floodplain, MIKE FLOOD can directly compute the flow pattern based on topography, building placement, and resistance.

Within the MIKE FLOOD model domain for the Ross Valley, the one-dimensional model, MIKE 11, covers the mainstem of Corte Madera Creek from the Bay upstream to the San Anselmo Creek confluence with Deer Park Creek, which is about 600 ft upstream of the Fairfax Creek confluence, and the lower portions of four major tributaries; Fairfax Creek, Sleepy Hollow Creek, Sorich Creek, and Ross Creek. The two-dimensional model MIKE 21 is implemented using detailed digitized topographic data for the river basin and the river floodplain at a grid cell size of 10 meters by 10 meters. Cells mostly occupied by buildings within the MIKE 21 model domain (i.e., more than 50% of the cell is occupied by building footprint) were de-activated by setting a high elevation in the DEM. The MIKE 21 model domain was oriented in the main flow direction along the San Anselmo Avenue in downtown San Anselmo. The MIKE 11 and MIKE 21 models were coupled using lateral links (i.e., lateral weir structures) along the top of the creek banks. The MIKE FLOOD model was first calibrated to the observed high water marks for the December 31, 2005 flood event and then verified to the observed high water marks for the January 4, 1982 flood event. The flow inputs for the MIKE FLOOD model were generated by the Stetson-developed HEC-HMS hydrologic model application for the Ross Valley watershed.

Analysis of Event Damage

Estimated flood damage was evaluated on a parcel-by-parcel basis using assumed first finished floor elevations of buildings[2] and the floodplain mapping results. By overlaying these assumed first finished floor elevations on the model-derived floodplain maps, depth of inundation was estimated for all buildings. Depths of inundation for seven selected flood recurrences/probabilities (summarized in Table 1) were estimated under without-Project and with-Project conditions.

In order to estimate flood damage, the functional relationship between depth of inundation and damage was necessary. Damage increases with depth of inundation. Depth-damage functions for residential and nonresidential buildings, with one story and no basement, developed by the U.S. Army Corps of Engineers (USACE) were used in the analysis (see Tables 2 and 3 and Figures 9 and 10). These depth-damage functions express damage, in terms of percentage of the total construction value of the building, as a function of depth of inundation. These depth-damage functions account for damage that can occur when the floodwater surface is below the first finished floor elevation. The maximum damage does not exceed the construction value of the building, which was estimated assuming a unit construction value of $200 per square foot. Data on building square footages and building types (residential, commercial, industrial, and public) were derived from the County Assessors database. In addition to damage to the building, damage to contents within the building was also considered. Content values were estimated using the DWR-recommended content-to-structure value ratios, which are typically approximately 50 percent for residential, 100% for commercial, 150% for industrial, and 100% for public buildings. Depth-damage functions for contents within residential and commercial buildings developed by the USACE were used in the analysis (see Tables 2 and 3 and Figures 9 and 10).

[2] Since survey data are available for few first finished floor elevations of buildings in the Ross Valley, assumptions were necessary. For the purpose of this engineering economic analysis, the first finished floor elevations of buildings upstream of Bon Air Road were uniformly assumed to be 1.0 ft above the ground elevation, and the first finished floor elevations of buildings downstream of Bon Air Road were assumed to be at the 100-year flood water surface elevation simulated under existing conditions. The estimation of flood damage is sensitive to this assumption. The reasonableness of this assumption was evaluated by examining the limited survey data on first finished floor elevations of buildings in the Ross Valley and survey data on first finished floor elevations of buildings in Mill Valley performed by the County in 2009. This examination verified that the assumptions are reasonable.

Table 2 USACE Residential Depth-Damage Functions
(One Story, No Basement)

First Floor Inundation Depth (ft)	**Damage to Building** (% of Construction Value)	**Damage to Contents** (% of Construction Value)
-2	0%	0%
-1	2.50%	2.40%
0	13.40%	8.10%
1	23.30%	13.30%
2	32.10%	17.90%
3	40.10%	22.00%
4	47.10%	25.70%
5	53.20%	28.80%
6	58.60%	31.50%
7	63.20%	33.80%
8	67.20%	35.70%
9	70.50%	37.20%
10	73.20%	38.40%
11	75.40%	39.20%
12	77.20%	39.70%
13	78.50%	40.00%
14	79.50%	40.00%
15	80.20%	40.00%
16	80.70%	40.00%

Note:
The residential depth-damage function was also used on buildings zoned as "tax exempt" which includes schools and government buildings.

Figure 9 USACE Residential Depth-Damage Curves
(One Story, No Basement)

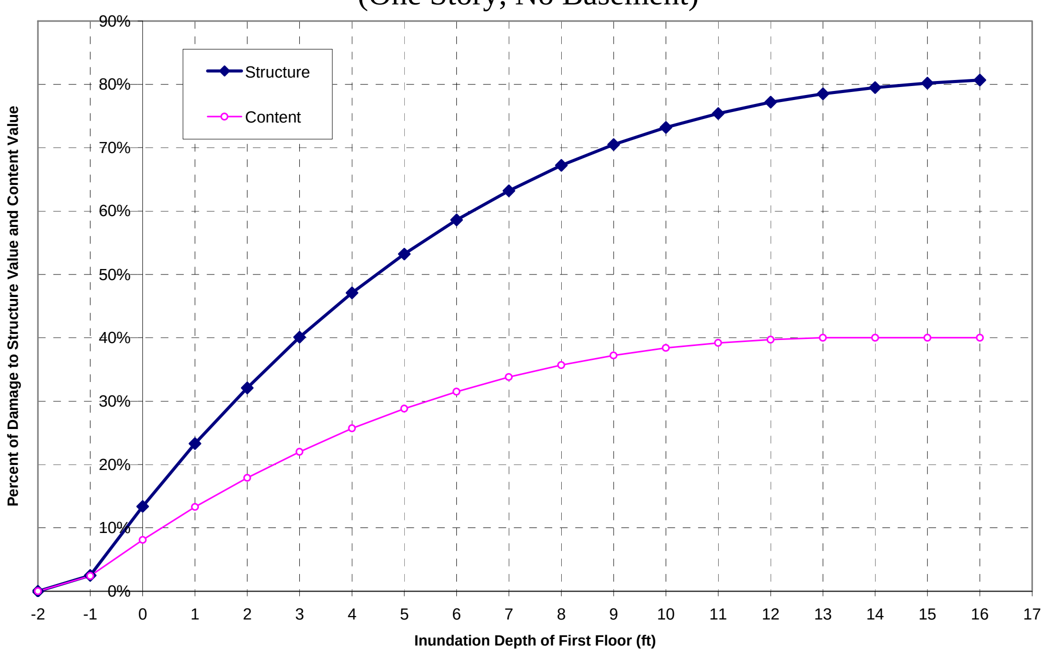
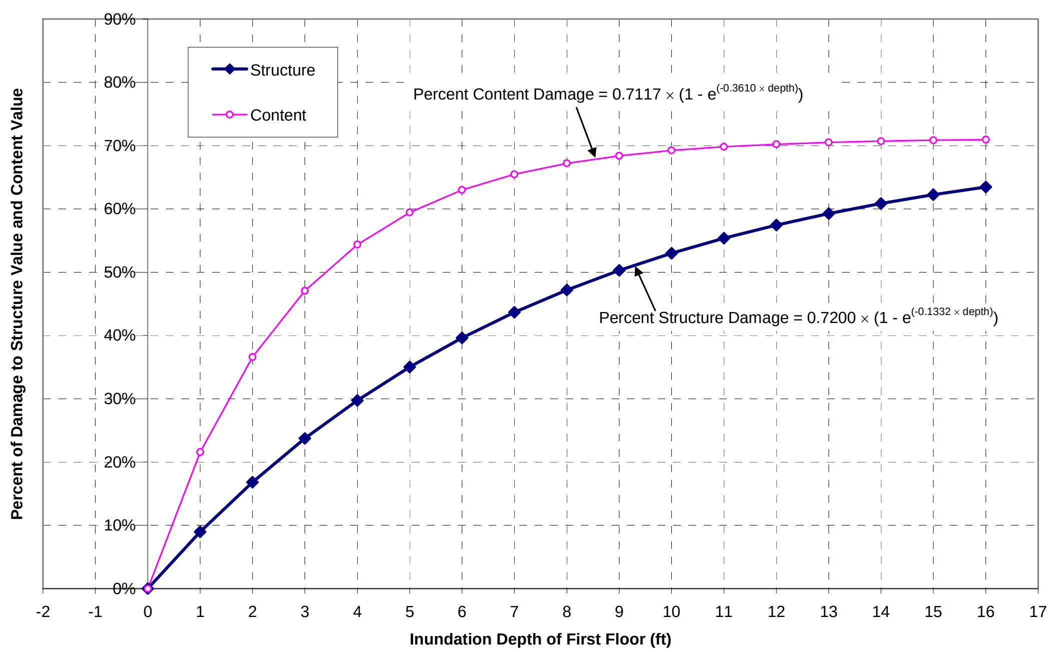


Table 3 USACE Non-Residential Depth-Damage Functions (No Basement)

First Floor Inundation Depth (ft)	**Damage to Building** (% of Construction Value)	**Damage to Contents** (% of Contents Value)
0	0.00%	0.00%
1	8.98%	21.57%
2	16.84%	36.60%
3	23.72%	47.07%
4	29.74%	54.38%
5	35.01%	59.46%
6	39.62%	63.01%
7	43.66%	65.48%
8	47.19%	67.21%
9	50.29%	68.41%
10	53.00%	69.24%
11	55.37%	69.83%
12	57.44%	70.23%
13	59.26%	70.52%
14	60.85%	70.72%
15	62.24%	70.85%
16	63.45%	70.95%

Note:
Contents value was assumed at 100% of structure value for commercial and 150% for industrial.

Figure 10 USACE Non-Residential Depth-Damage Curves

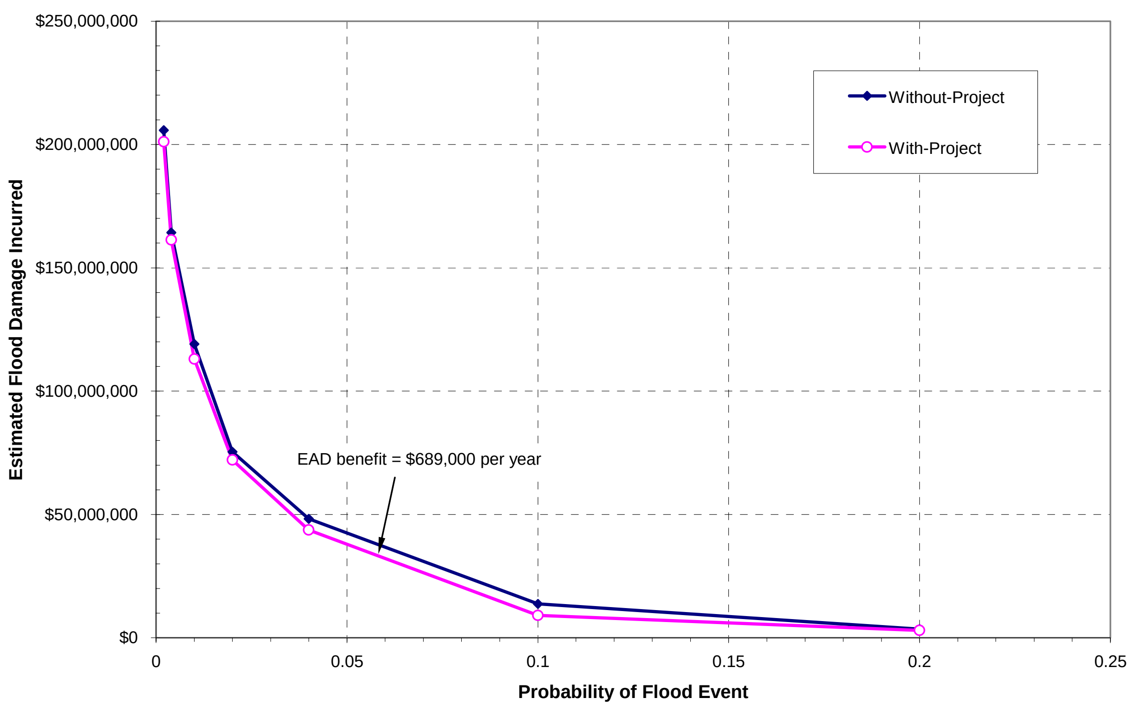


By coupling the depth of inundation-probability information with the depth of inundation-damage functions, damage to buildings and contents was evaluated for seven selected flood recurrences/probabilities (as summarized in Table 1) under without-Project and with-Project conditions. The incremental damage that the Project prevents for a given flood recurrence/probability can be estimated by subtracting the with-Project damage from the without-Project damage. Damages for the 5-year, 10-year, 25-year, 50-year, 100-year, 250-year, and 500-year flood recurrences/probabilities under without-Project and with-Project conditions are given in Table 4 and shown in Figure 10.

Table 4 Flood Damages under Without- and With-Project Conditions for a Range of Flood Events

Hydrologic Event	Event Probability	Without-Project			With-Project			Event Benefit ($)
		Damage to Building ($)	Damage to Contents ($)	Total Damage ($)	Damage to Building ($)	Damage to Contents ($)	Total Damage ($)	
5-Year	0.200	$1,758,000	$1,728,000	**$3,485,000**	$1,519,000	$1,447,000	**$2,966,000**	**$519,000**
10-Year	0.100	$7,530,000	$6,218,000	**$13,749,000**	$4,560,000	$4,544,000	**$9,104,000**	**$4,645,000**
25-Year	0.040	$23,067,000	$25,127,000	**$48,194,000**	$20,197,000	$23,525,000	**$43,722,000**	**$4,472,000**
50-Year	0.020	$35,104,000	$40,318,000	**$75,422,000**	$33,525,000	$38,613,000	**$72,138,000**	**$3,284,000**
100-Year	0.010	$54,330,000	$64,778,000	**$119,108,000**	$51,261,000	$61,788,000	**$113,050,000**	**$6,058,000**
250-Year	0.004	$74,965,000	$89,308,000	**$164,272,000**	$73,526,000	$87,838,000	**$161,364,000**	**$2,909,000**
500-Year	0.002	$93,003,000	$112,833,000	**$205,836,000**	$90,865,000	$110,279,000	**$201,145,000**	**$4,691,000**

Figure 10 Flood Damage - Probability Curves



Analysis of Expected Annual Damage

Expected annual damage, also called the average annual damage, is the probability-weighted average of all possible annual damages (i.e., annual damages that could occur under the full range of flood recurrences/probabilities). As expected, the damage-probability function assigns a higher damage to the larger magnitude, rarer (i.e., low probability) floods and, conversely, assigns lower damage to the smaller magnitude, more frequent (i.e., higher probability) floods. Expected annual damage is the summation of all the possible products of probability times damage that are reflected in the damage-probability function, which is represented by the area below the respective curve shown in Figure 10. Expected annual damages and expected prevented annual damages for without-Project and with-Project conditions are given in Table 5. The expected prevented annual damage by the Project is estimated to be approximately $689,000.

Table 5 Expected Annual Damages and Prevented Annual Damages for Without- and With-Project Conditions

Condition	Expected Annual Damage ($/year)	Expected Prevented Annual Damage (i.e. Benefit; $/year)
Without-Project	6,149,000	-
With-Project	5,460,000	689,000

Detailed Results of Flood Damage Analysis -- Without-Project Conditions

(Assumptions: First Floor Elevation = Ground Elevation + 1.0 ft for Buildings Upstream of Bon Air Road
First Floor Elevation = Existing 100-Year WSE for Buildings Downstream of Bon Air Road)

For Ross Valley - Corte Madera Creek

Flood Events

Ross Valley Watershed	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Number of Inundated Buildings	191	539	1,302	1,547	2,090	2,624	2,920
Number of Inundated Parcels	122	334	793	938	1,414	1,526	1,755
Total Structural Damage	$1,757,667	$7,530,115	$23,067,411	$35,103,940	$54,330,051	$74,964,558	$93,002,908
Total Content Damange	$1,727,703	$6,218,488	$25,126,654	$40,317,768	$64,777,721	$89,307,893	$112,833,381
Total Damage*	**$3,485,370**	**$13,748,604**	**$48,194,065**	**$75,421,708**	**$119,107,772**	**$164,272,451**	**$205,836,289**

Total Damage by Category Type[1]	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$908	$12,899,513	$26,127,235	$42,794,149	$60,353,881	$72,819,786
Industrial	$0	$0	$0	$0	$0	$1,460,925	$1,595,044
Residential	$3,485,370	$13,746,225	$34,912,111	$45,477,113	$59,586,241	$76,425,266	$93,001,778
Tax Exempt	$0	$1,471	$382,440	$3,817,360	$16,727,382	$26,032,380	$38,419,681
Total	**$3,485,370**	**$13,748,604**	**$48,194,065**	**$75,421,708**	**$119,107,772**	**$164,272,451**	**$205,836,289**

Total Damage by Category	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Total Commercial Content	$0	$657	$8,883,030	$17,556,013	$28,181,155	$39,244,454	$47,158,850
Total Commercial Structure	$0	$250	$4,016,483	$8,571,222	$14,612,994	$21,109,427	$25,660,936
Total Industrial Content	$0	$0	$0	$0	$0	$785,752	$845,170
Total Industrial Structural	$0	$0	$0	$0	$0	$675,173	$749,874
Total Residential Content	$1,727,703	$6,216,762	$15,971,672	$20,085,871	$25,169,133	$31,590,494	$38,815,446
Total Residential Structural	$1,757,667	$7,529,463	$18,940,440	$25,391,242	$34,417,108	$44,834,772	$54,186,332
Total Tax Exempt Content	$0	$0	$0	$0	$0	$0	$0
Total Tax Exempt Structural	$0	$0	$0	$0	$0	$0	$0
Total	**$3,485,370**	**$13,747,133**	**$47,811,625**	**$71,604,348**	**$102,380,390**	**$138,240,071**	**$167,416,608**

By City/Town

Total Damage by City/Town[o]	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Corte Madera	$0	$0	$0	$0	$0	$420,275	$1,219,045
Fairfax	$1,564,347	$2,766,346	$3,109,559	$3,955,549	$4,838,072	$6,157,815	$6,549,028
Greenbrae	$0	$0	$0	$0	$0	$1,642,733	$2,101,628
Kentfield	$0	$4,402,003	$7,104,709	$9,690,380	$21,452,902	$28,942,894	$45,221,019
Larkspur	$0	$20,361	$724,120	$937,797	$2,256,430	$5,400,535	$9,710,611
Ross	$1,608,846	$5,501,183	$10,259,433	$12,093,355	$14,819,919	$17,628,498	$21,376,567
San Anselmo	$312,177	$1,058,711	$26,996,243	$48,744,628	$75,740,448	$104,079,701	$119,658,389
Total	**$3,485,370**	**$13,748,604**	**$48,194,065**	**$75,421,708**	**$119,107,772**	**$164,272,451**	**$205,836,289**

Total Inundated Parcels by City/Town[o]	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Corte Madera	0	0	0	0	29	39	46
Fairfax	65	89	110	142	181	166	173
Greenbrae	0	0	0	0	79	102	103
Kentfield	0	84	108	112	128	129	210
Larkspur	0	1	16	17	196	265	346
Ross	45	118	186	207	223	221	226
San Anselmo	12	42	373	460	578	604	651
Total	**122**	**334**	**793**	**938**	**1,414**	**1,526**	**1,755**

Total Damage by Category for Corte Madera	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$0	$0	$0	$0	$240,138	$737,577
Industrial	$0	$0	$0	$0	$0	$20,330	$22,500
Residential	$0	$0	$0	$0	$0	$159,807	$458,969
Tax Exempt	$0	$0	$0	$0	$0	$0	$0
Subtotal	**$0**	**$0**	**$0**	**$0**	**$0**	**$420,275**	**$1,219,045**

Total Damage by Category for Fairfax	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$908	$17,907	$31,826	$46,891	$71,397	$86,098
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$1,564,347	$2,765,439	$3,091,652	$3,923,723	$4,791,182	$6,059,872	$6,394,974
Tax Exempt	$0	$0	$0	$0	$0	$26,547	$67,956
Subtotal	**$1,564,347**	**$2,766,346**	**$3,109,559**	**$3,955,549**	**$4,838,072**	**$6,157,815**	**$6,549,028**

Total Damage by Category for Greenbrae	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$0	$0	$0	$0	$82,350	$214,486
Industrial	$0	$0	$0	$0	$0	$1,440,595	$1,572,545
Residential	$0	$0	$0	$0	$0	$119,788	$314,597
Tax Exempt	$0	$0	$0	$0	$0	$0	$0
Subtotal	**$0**	**$0**	**$0**	**$0**	**$0**	**$1,642,733**	**$2,101,628**

Total Damage by Category for Kentfield	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$0	$0	$0	$2,060	$161,340	$1,252,112
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$0	$4,400,532	$7,090,910	$8,247,146	$10,148,243	$12,851,956	$19,481,508
Tax Exempt	$0	$1,471	$13,799	$1,443,235	$11,302,599	$15,929,598	$24,487,398
Subtotal	**$0**	**$4,402,003**	**$7,104,709**	**$9,690,380**	**$21,452,902**	**$28,942,894**	**$45,221,019**

Total Damage by Category for Larkspur	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$0	$0	$0	$0	$482	$1,173
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$0	$20,361	$724,120	$937,794	$2,252,069	$5,254,500	$9,414,147
Tax Exempt	$0	$0	$0	$2	$4,361	$145,553	$295,292
Subtotal	**$0**	**$20,361**	**$724,120**	**$937,797**	**$2,256,430**	**$5,400,535**	**$9,710,611**

Total Damage by Category for Ross	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$0	$35,523	$110,464	$334,350	$636,016	$903,176
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$1,608,846	$5,501,183	$10,223,672	$11,967,595	$14,394,819	$16,671,559	$19,232,272
Tax Exempt	$0	$0	$237	$15,296	$90,750	$320,923	$1,241,119
Subtotal	**$1,608,846**	**$5,501,183**	**$10,259,433**	**$12,093,355**	**$14,819,919**	**$17,628,498**	**$21,376,567**

Total Damage by Category for San Anselmo	**5yr**	**10yr**	**25yr**	**50yr**	**100yr**	**250yr**	**500yr**
Commercial	$0	$0	$12,846,083	$25,984,946	$42,410,848	$59,162,158	$69,625,164
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$312,177	$1,058,711	$13,781,757	$20,400,855	$27,999,928	$35,307,783	$37,705,310
Tax Exempt	$0	$0	$368,403	$2,358,827	$5,329,672	$9,609,759	$12,327,916
Subtotal	**$312,177**	**$1,058,711**	**$26,996,243**	**$48,744,628**	**$75,740,448**	**$104,079,701**	**$119,658,389**

Notes:

* All damage estimates based on $200/sq. ft. of building footprint.
[1] Categories summarized from tax records.
[o] City/Town as designated in tax records.

Detailed Results of Flood Damage Analysis -- With-Project Conditions

(Assumptions: First Floor Elevation = Ground Elevation + 1.0 ft for Buildings Upstream of Bon Air Road
First Floor Elevation = Existing 100-Year WSE for Buildings Downstream of Bon Air Road)

For Ross Valley - Corte Madera Creek

Flood Events

Ross Valley Watershed	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Number of Inundated Buildings	165	471	1,250	1,509	2,065	2,590	2,852
Number of Inundated Parcels	106	292	757	929	1,393	1,506	1,698
Total Structural Damage	$1,519,155	$4,559,801	$20,196,939	$33,524,815	$51,261,452	$73,526,040	$90,865,421
Total Content Damange	$1,446,946	$4,544,106	$23,524,887	$38,613,383	$61,788,400	$87,837,904	$110,279,392
Total Damage*	**$2,966,101**	**$9,103,907**	**$43,721,826**	**$72,138,199**	**$113,049,852**	**$161,363,943**	**$201,144,814**

Total Damage by Category Type[1]	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$2,225	$12,853,525	$25,977,185	$42,624,499	$60,053,239	$72,407,103
Industrial	$0	$0	$0	$0	$0	$1,440,563	$1,583,697
Residential	$2,966,101	$9,101,683	$30,502,026	$43,791,592	$56,021,677	$74,578,907	$89,928,170
Tax Exempt	$0	$0	$366,275	$2,369,422	$14,403,676	$25,291,235	$37,225,843
Total	**$2,966,101**	**$9,103,907**	**$43,721,826**	**$72,138,199**	**$113,049,852**	**$161,363,943**	**$201,144,814**

Total Damage by Category	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Total Commercial Content	$0	$1,610	$8,851,478	$17,455,364	$28,065,338	$39,037,879	$46,872,350
Total Commercial Structure	$0	$614	$4,002,047	$8,521,821	$14,559,161	$21,015,360	$25,534,754
Total Industrial Content	$0	$0	$0	$0	$0	$776,730	$840,144
Total Industrial Structural	$0	$0	$0	$0	$0	$663,832	$743,554
Total Residential Content	$1,446,946	$4,542,496	$14,413,118	$19,516,723	$23,864,177	$30,836,712	$37,378,996
Total Residential Structural	$1,519,155	$4,559,187	$16,088,908	$24,274,868	$32,157,500	$43,742,195	$52,549,174
Total Tax Exempt Content	$0	$0	$0	$0	$0	$0	$0
Total Tax Exempt Structural	$0	$0	$0	$0	$0	$0	$0
Total	**$2,966,101**	**$9,103,907**	**$43,355,551**	**$69,768,776**	**$98,646,176**	**$136,072,708**	**$163,918,971**

By City/Town

Total Damage by City/Town[o]	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Corte Madera	$0	$0	$0	$0	$0	$215,567	$938,846
Fairfax	$1,564,347	$2,240,272	$3,109,559	$3,955,549	$4,838,072	$6,157,814	$6,549,029
Greenbrae	$0	$0	$0	$0	$0	$1,567,825	$2,005,608
Kentfield	$0	$2,492,457	$5,102,819	$7,556,518	$17,815,647	$27,638,868	$42,239,436
Larkspur	$0	$0	$426,547	$789,523	$1,620,590	$4,795,984	$9,187,621
Ross	$1,093,730	$3,351,595	$8,223,744	$10,957,237	$13,084,701	$17,103,230	$20,432,392
San Anselmo	$308,024	$1,019,583	$26,859,157	$48,879,372	$75,690,842	$103,884,656	$119,791,880
Total	**$2,966,101**	**$9,103,907**	**$43,721,826**	**$72,138,199**	**$113,049,852**	**$161,363,943**	**$201,144,814**

Total Inundated Parcels by City/Town[o]	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Corte Madera	0	0	0	0	29	33	45
Fairfax	65	88	108	145	181	166	173
Greenbrae	0	0	0	0	79	102	102
Kentfield	0	68	96	110	126	126	164
Larkspur	0	0	14	16	183	252	340
Ross	29	95	168	191	217	223	223
San Anselmo	12	41	371	467	578	604	651
Total	**106**	**292**	**757**	**929**	**1,393**	**1,506**	**1,698**

Total Damage by Category for Corte Madera	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$0	$0	$0	$0	$126,701	$542,723
Industrial	$0	$0	$0	$0	$0	$20,050	$22,258
Residential	$0	$0	$0	$0	$0	$68,816	$373,865
Tax Exempt	$0	$0	$0	$0	$0	$0	$0
Subtotal	**$0**	**$0**	**$0**	**$0**	**$0**	**$215,567**	**$938,846**

Total Damage by Category for Fairfax	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$2,225	$17,907	$31,826	$46,891	$71,397	$86,098
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$1,564,347	$2,238,048	$3,091,652	$3,923,723	$4,791,182	$6,059,870	$6,394,975
Tax Exempt	$0	$0	$0	$0	$0	$26,547	$67,956
Subtotal	**$1,564,347**	**$2,240,272**	**$3,109,559**	**$3,955,549**	**$4,838,072**	**$6,157,814**	**$6,549,029**

Total Damage by Category for Greenbrae	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$0	$0	$0	$0	$69,856	$197,920
Industrial	$0	$0	$0	$0	$0	$1,420,512	$1,561,439
Residential	$0	$0	$0	$0	$0	$77,457	$246,249
Tax Exempt	$0	$0	$0	$0	$0	$0	$0
Subtotal	**$0**	**$0**	**$0**	**$0**	**$0**	**$1,567,825**	**$2,005,608**

Total Damage by Category for Kentfield	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$0	$0	$0	$92	$137,609	$1,135,104
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$0	$2,492,457	$5,102,819	$7,535,457	$8,782,284	$12,271,664	$17,192,987
Tax Exempt	$0	$0	$0	$21,061	$9,033,271	$15,229,595	$23,911,345
Subtotal	**$0**	**$2,492,457**	**$5,102,819**	**$7,556,518**	**$17,815,647**	**$27,638,868**	**$42,239,436**

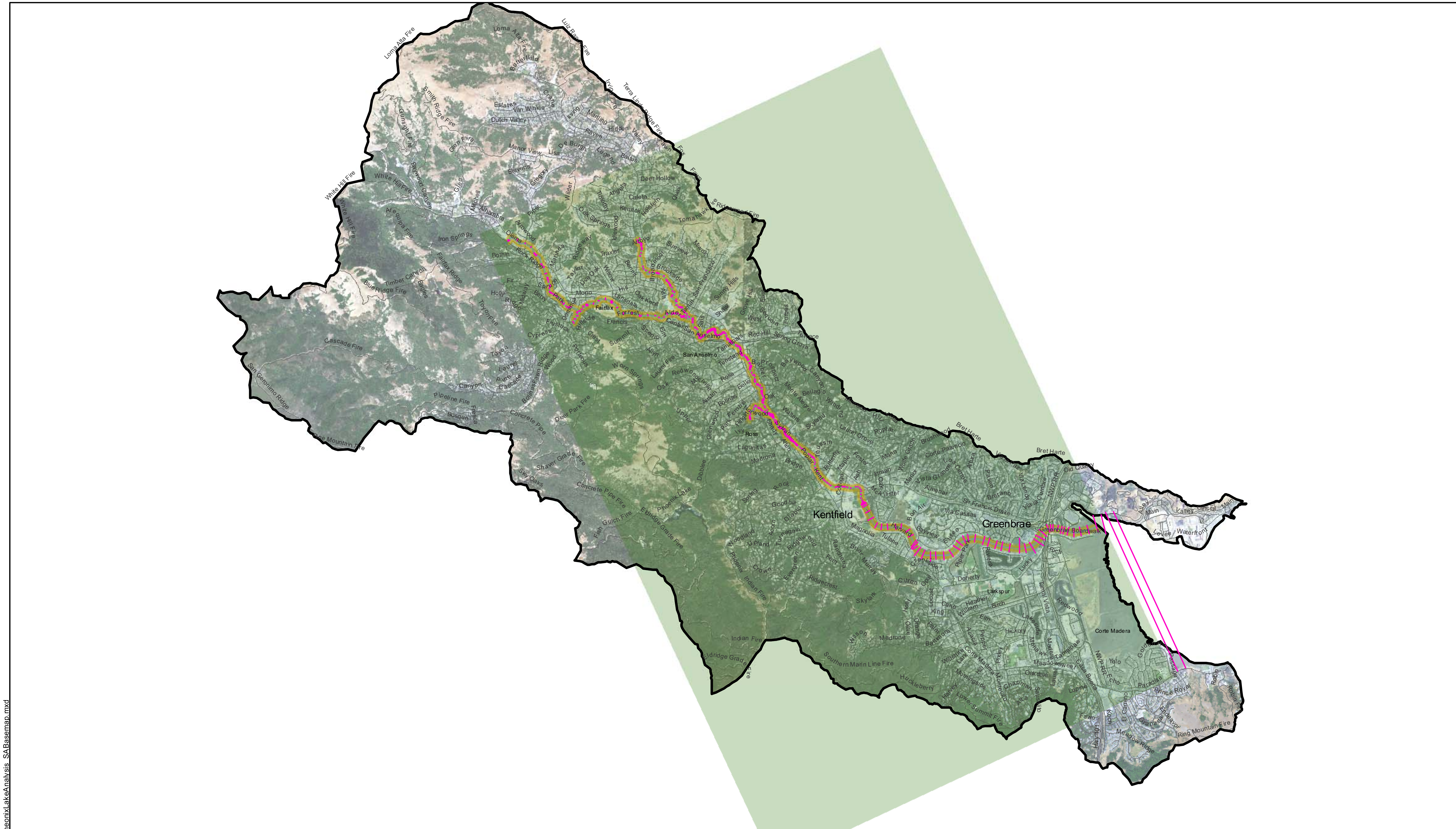
Total Damage by Category for Larkspur	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$0	$0	$0	$0	$408	$1,087
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$0	$0	$426,547	$789,523	$1,619,150	$4,675,604	$8,928,033
Tax Exempt	$0	$0	$0	$0	$1,440	$119,972	$258,501
Subtotal	**$0**	**$0**	**$426,547**	**$789,523**	**$1,620,590**	**$4,795,984**	**$9,187,621**

Total Damage by Category for Ross	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$0	$10,343	$45,178	$226,180	$579,070	$870,710
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$1,093,730	$3,351,595	$8,213,401	$10,911,085	$12,806,803	$16,186,829	$18,895,363
Tax Exempt	$0	$0	$0	$974	$51,719	$337,331	$666,318
Subtotal	**$1,093,730**	**$3,351,595**	**$8,223,744**	**$10,957,237**	**$13,084,701**	**$17,103,230**	**$20,432,392**

Total Damage by Category for San Anselmo	5yr	10yr	25yr	50yr	100yr	250yr	500yr
Commercial	$0	$0	$12,825,275	$25,900,181	$42,351,337	$59,068,199	$69,573,461
Industrial	$0	$0	$0	$0	$0	$0	$0
Residential	$308,024	$1,019,583	$13,667,606	$20,631,804	$28,022,259	$35,238,667	$37,896,697
Tax Exempt	$0	$0	$366,275	$2,347,387	$5,317,246	$9,577,791	$12,321,722
Subtotal	**$308,024**	**$1,019,583**	**$26,859,157**	**$48,879,372**	**$75,690,842**	**$103,884,656**	**$119,791,880**

Notes:

* All damage estimates based on $200/sq. ft. of building footprint.
[1] Categories summarized from tax records.
[o] City/Town as designated in tax records.



Mike 11 Channel Cross-section
Creek
Road
Mike 21 Model Domain (2-D)
Mike 11 Model Domain (1-D)
Ross Valley Watershed Boundary

STETSON ENGINEERS INC.

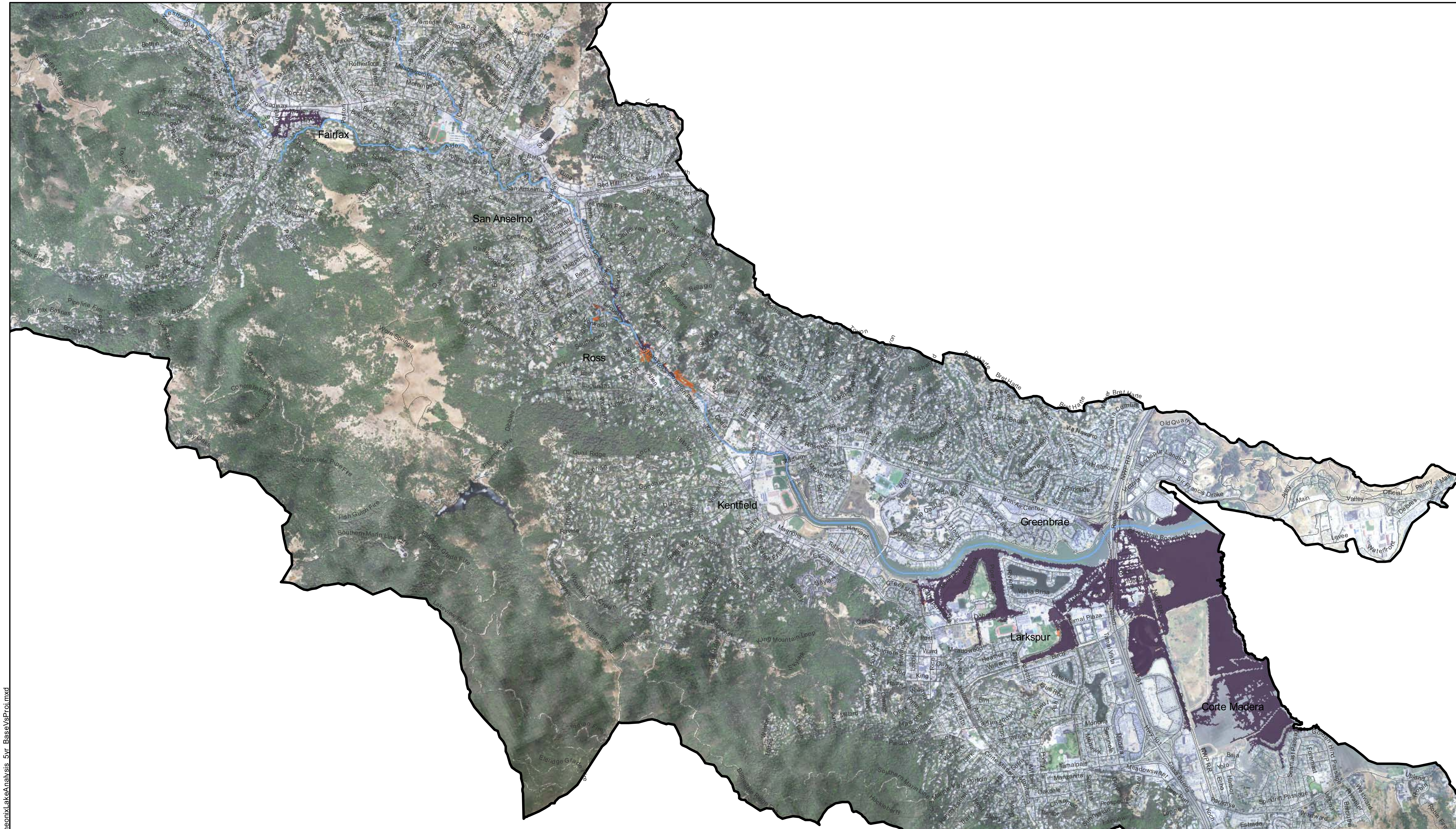
MIKE FLOOD MODEL DOMAIN
ROSS VALLEY WATERSHED

0 0.5 1 Miles

N

FIGURE 1

J:\n2367\RossValleyEcon_PheonixLakeAnalysis_SABasemap.mxd



STETSON ENGINEERS INC.

Ross Valley Watershed Boundary
Creek
Road

5yr Flood Inundation, Without-Project Conditions
5yr Flood Inundation, With-Project Conditions
5yr Flood Inundation, With- and Without-Project Conditions

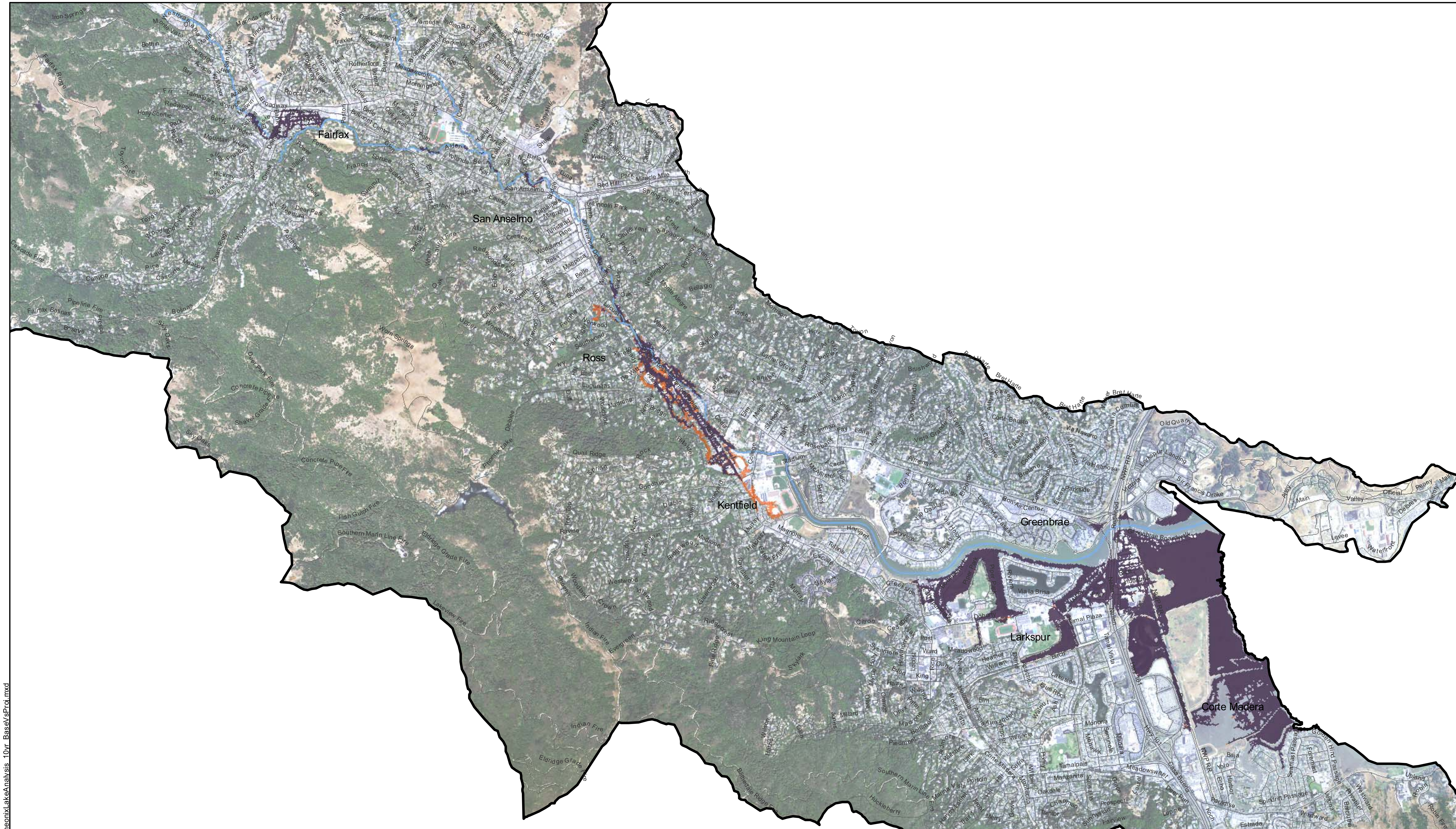
5yr FLOOD EVENT INUNDATION
WITHOUT-PROJECT VS. WITH-PROJECT CONDITIONS
ROSS VALLEY WATERSHED

0 0.5 1 Miles

N

FIGURE 2

J:\n2367\RossValleyEcon_PheonixLakeAnalysis_5yr_BaseVsProj.mxd



Ross Valley Watershed Boundary
Creek
Road

10yr Flood Inundation, Without-Project Conditions
10yr Flood Inundation, With-Project Conditions
10yr Flood Inundation, With- and Without-Project Conditions

10yr FLOOD EVENT INUNDATION
WITHOUT-PROJECT VS. WITH-PROJECT CONDITIONS
ROSS VALLEY WATERSHED

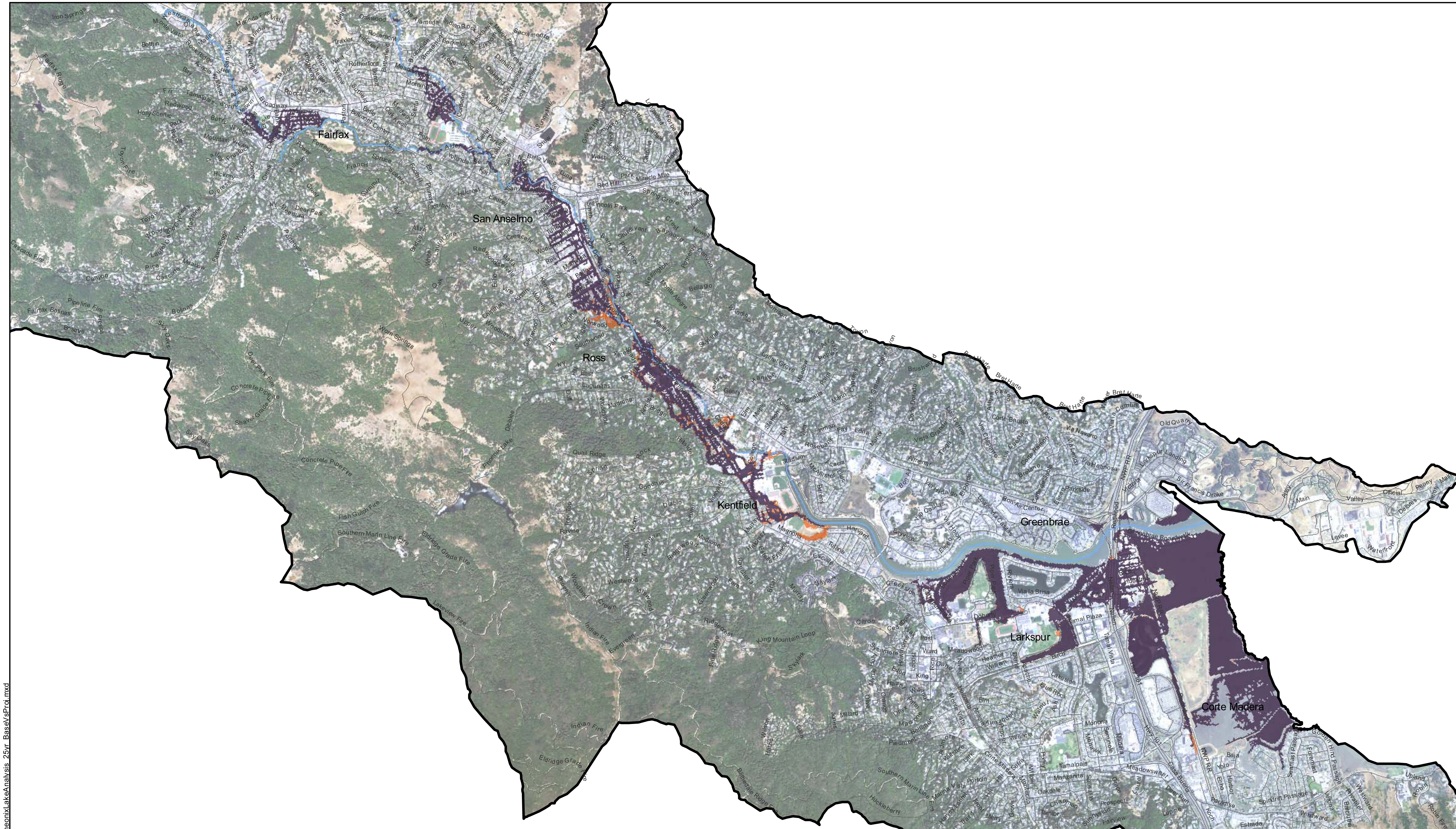
0 0.5 1 Miles

N

STETSON ENGINEERS INC.

FIGURE 3

J:\n2367\RossValleyEcon_PheonixLakeAnalysis_10yr_BaseVsProj.mxd



STETSON ENGINEERS INC.

Ross Valley Watershed Boundary
Creek
Road

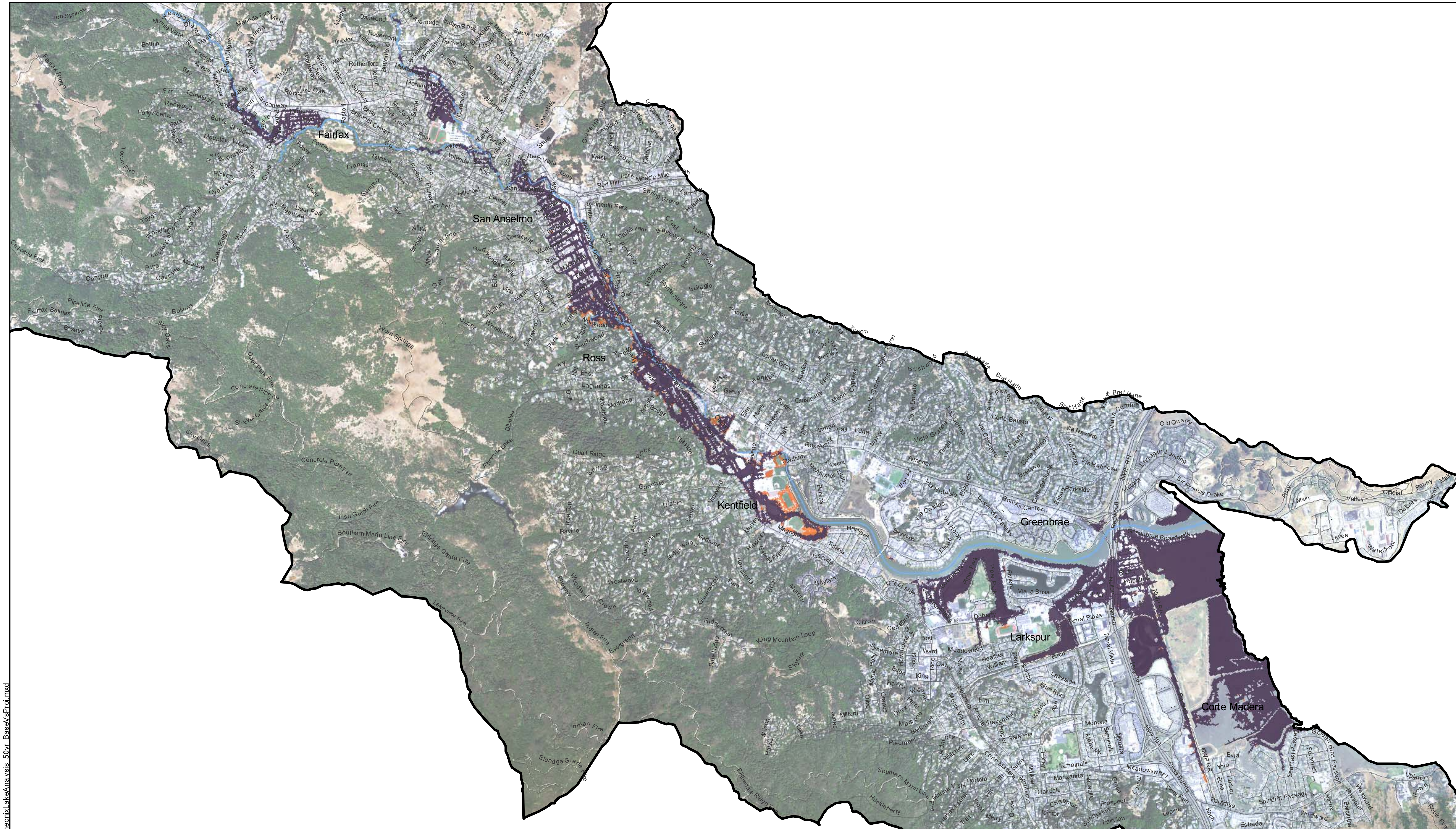
25yr Flood Inundation, Without-Project Conditions
25yr Flood Inundation, With-Project Conditions
25yr Flood Inundation, With- and Without-Project Conditions

25yr FLOOD EVENT INUNDATION
WITHOUT-PROJECT VS. WITH-PROJECT CONDITIONS
ROSS VALLEY WATERSHED

0 0.5 1 Miles

N

FIGURE 4



STETSON ENGINEERS INC.

Ross Valley Watershed Boundary

Creek

Road

50yr Flood Inundation, Without-Project Conditions

50yr Flood Inundation, With-Project Conditions

50yr Flood Inundation, With- and Without-Project Conditions

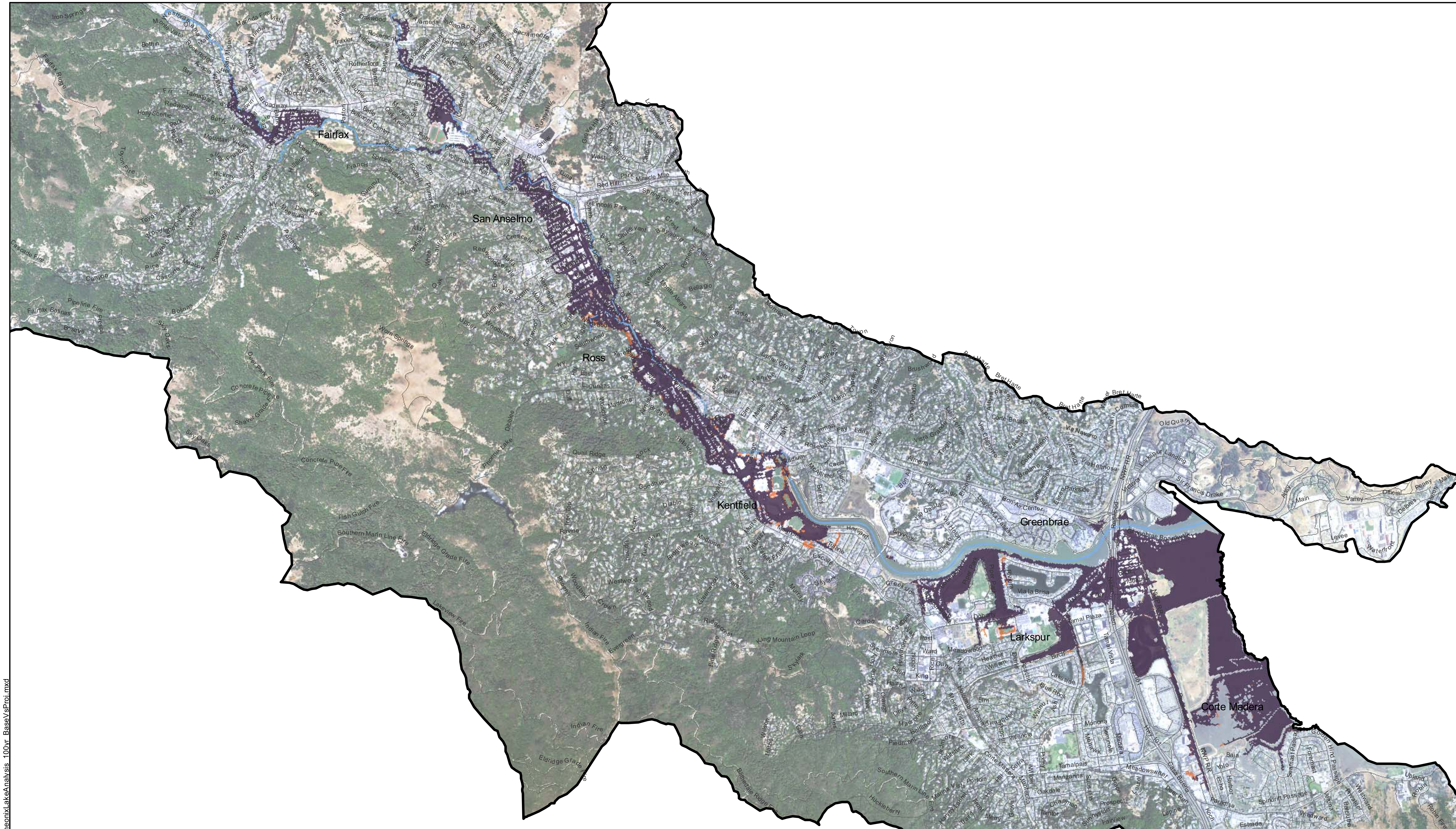
50yr FLOOD EVENT INUNDATION
WITHOUT-PROJECT VS. WITH-PROJECT CONDITIONS
ROSS VALLEY WATERSHED

0 0.5 1 Miles

N

FIGURE 5

J:\jn2367\RossValleyEcon_PheonixLakeAnalysis_50yr_BaseVsProj.mxd



STETSON ENGINEERS INC.

Ross Valley Watershed Boundary
Creek
Road

100yr Flood Inundation, Without-Project Conditions
100yr Flood Inundation, With-Project Conditions
100yr Flood Inundation, With- and Without-Project Conditions

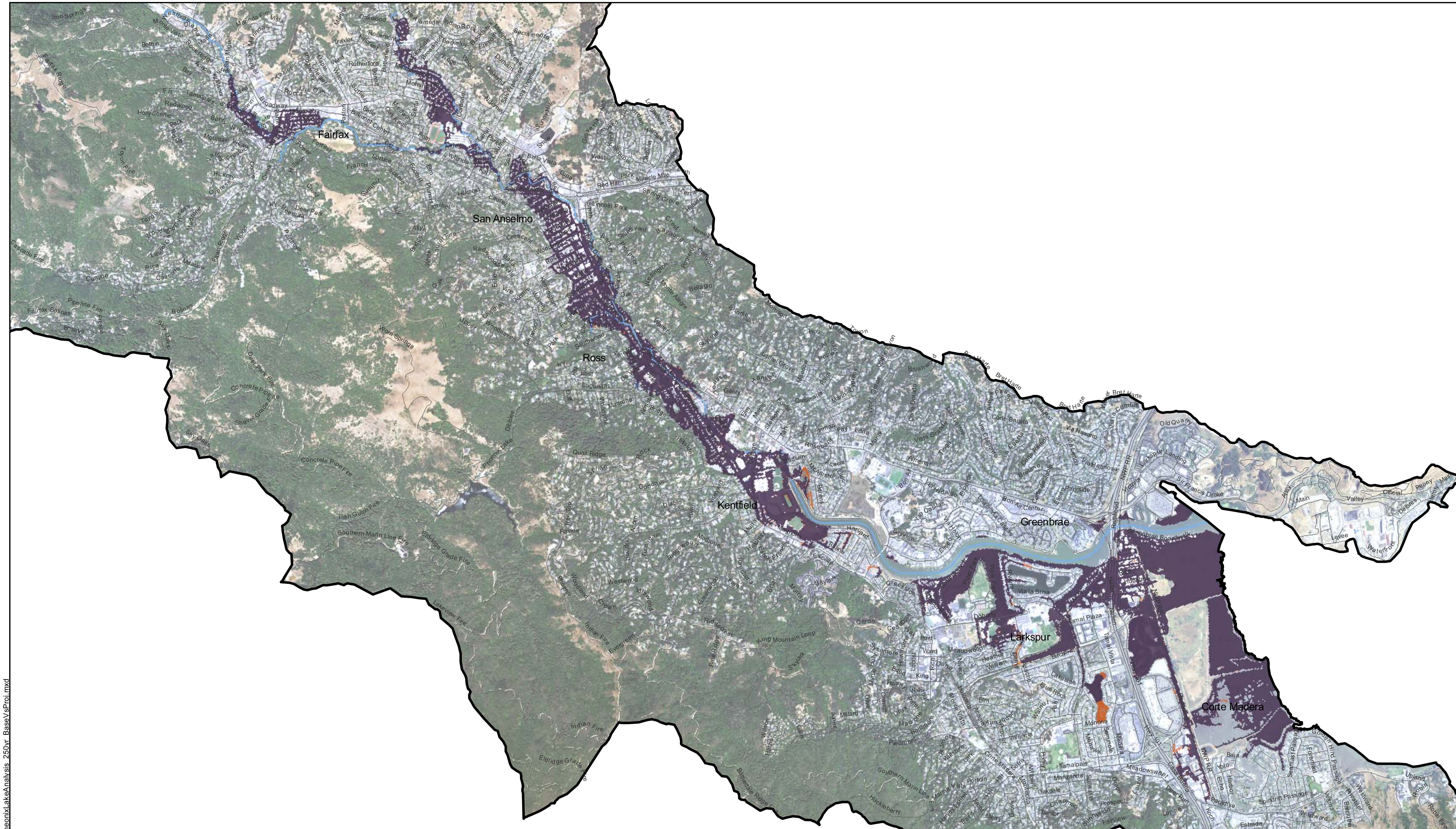
100yr FLOOD EVENT INUNDATION
WITHOUT-PROJECT VS. WITH-PROJECT CONDITIONS
ROSS VALLEY WATERSHED

0 0.5 1 Miles

N

FIGURE 6

J:\jn2367\RossValleyEcon_PheonixLakeAnalysis_100yr_BaseVsProj.mxd



STETSON ENGINEERS INC.

Ross Valley Watershed Boundary
Creek
Road

250yr Flood Inundation, Without-Project Conditions
250yr Flood Inundation, With-Project Conditions
250yr Flood Inundation, With- and Without-Project Conditions

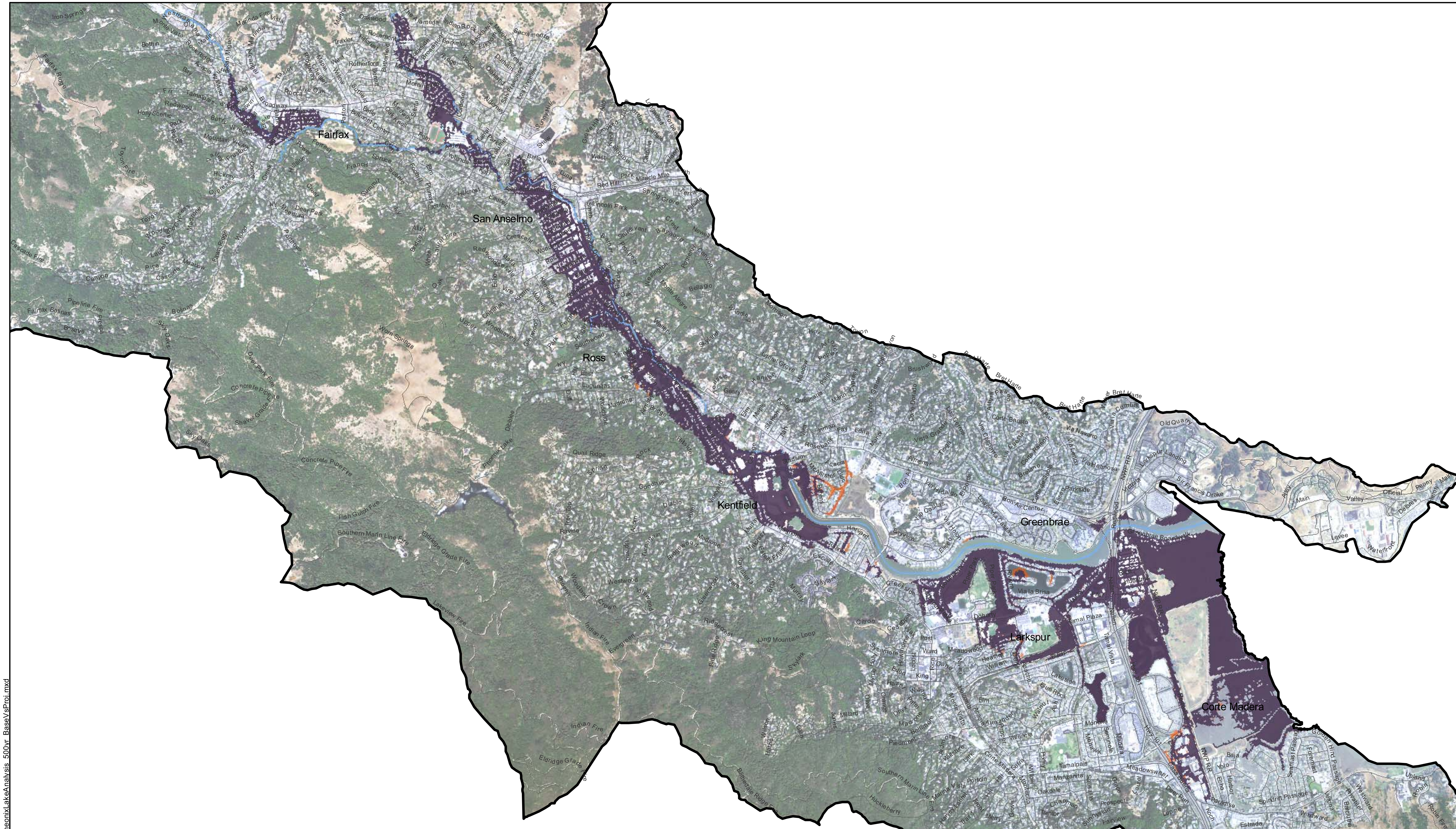
250yr FLOOD EVENT INUNDATION
WITHOUT-PROJECT VS. WITH-PROJECT CONDITIONS
ROSS VALLEY WATERSHED

0 0.5 1 Miles

N

FIGURE 7

J:\jn2367\RossValleyEcon_PheonixLakeAnalysis_250yr_BaseVsProj.mxd



Ross Valley Watershed Boundary
Creek
Road

500yr Flood Inundation, Without-Project Conditions
500yr Flood Inundation, With-Project Conditions
500yr Flood Inundation, With- and Without-Project Conditions

500yr FLOOD EVENT INUNDATION
WITHOUT-PROJECT VS. WITH-PROJECT CONDITIONS
ROSS VALLEY WATERSHED

0 0.5 1 Miles

STETSON ENGINEERS INC.

J:\n2367\RossValleyEcon_PheonixLakeAnalysis_500yr_BaseVsProj.mxd

FIGURE 8

APPENDIX 2 TO ATTACHMENT 7

SEISMIC FAILURE DAMAGE ANALYSIS OF PHOENIX LAKE DAM

Stetson Engineers Inc.
March 4, 2011

A seismic failure damage analysis was prepared for the Phoenix Lake dam for both without- and with-Project conditions. The analysis for without-Project conditions mainly included:

- Modifying the inundation extent of the existing Phoenix Lake dam failure inundation polygon originally from the State of California, Office of Emergency Services (1974);
- Calculating inundation depth based on the modified inundation extent; and,
- Estimating potential inundation damage.

Modification of the Inundation Extent of the Existing Phoenix Lake Dam Failure Inundation Polygon

The existing Phoenix Lake dam failure inundation polygon (Figure 1) is available in GIS format from the County of Marin (MarinMap.org). The metadata shows that this layer came from the State of California, Office of Emergency Services (1974), originally drawn against a 1:24,000 scale topographic map (Figure 2). When this polygon was overlaid on the County's 2 ft contours (MarinMap.org, 2004) and the recent Digital Elevation Model generated by the 2010 LiDAR data for the Corte Madera Creek floodplain (Stetson Engineers, 2010), it was found that the existing inundation extent needs to be modified for some areas to compute a realistic water surface elevation (WSE) for dam failure inundation.

It is known that the water surface extent (the inundation polygon edge) would correspond to the maximum WSE at any given cross-section and the WSE at both ends of a cross section would be the same. To achieve a higher level of accuracy, the existing polygon edge was first used to define the WSE at selected cross-sections and then interpolated the water surface elevation of the inundation. The cross sections were drawn to be perpendicular to the flow paths, judged based on the recent topography (Figure 3), assuming one-dimensional flow. Modifications to the cross section lateral extents were then made for the areas where the existing 1:24,000 scale inundation boundary seemed unrealistic. Figure 4 compares the existing inundation area (represented by the polygon) and the modified inundation area (represented by the yellow shaded area).

Calculation of Inundation Depth Based on the Modified Inundation Extent

The WSE contours of the modified inundation extent were then interpolated into a continuous raster layer using the Topo to Raster Arcmap toolbox application. The ground surface DEM was then subtracted from the interpolated WSE to give an inundation depth raster layer (Figure 4).

Estimation of Inundation Damage

Once the inundation depth was computed at each parcel, the inundation damage to a structure and contents within the structure was then estimated using the same method as described in Appendix 1 ("Floodplain Mapping and Engineering Economic Analysis of Phoenix Lake Flood Damage Reduction Project"). The potential inundation damage due to seismic failure under without-Project conditions is estimated to be approximately $277 million.

Under with-Project conditions, the normal operating lake level will be raised by 6 ft (from elevation 174 ft to 180 ft) and the normal storage volume will be increased by about 40% (from current 300 acre-ft to 420 acre-ft). Assuming that a 40% increase in reservoir storage would translate to a 40% increase in discharge at the peak of the flood wave, the water surface elevation at each of selected cross sections was estimated by increasing the flow area at each cross section by 40%. This analysis also assumed that the flow velocity at each cross section is the same for both without- and with-Project conditions. Figure 5 compares the inundation extent between without- and with-Project conditions.

The potential inundation damage due to seismic failure under with-Project conditions is estimated to be approximately $762 million.

Detailed Results of Pheonix Lake Dam Failure Flood Damage Analysis -- Without- and With-Project Conditions

(Assumptions: First Floor Elevation = Ground Elevation + 1.0 ft for Buildings Upstream of Bon Air Road
First Floor Elevation = Existing 100-Year WSE for Buildings Downstream of Bon Air Road)

For Ross Valley - Corte Madera Creek

Ross Valley Watershed	Without-Project Dam Failure	With-Project Dam Failure
Number of Inundated Buildings	1,473	1891
Number of Inundated Parcels	880	1154
Total Structural Damage	$150,157,994	$393,204,831
Total Content Damange	$127,020,728	$368,996,128
Total Damage*	**$277,178,722**	**$762,200,958**

Total Damage by Category Type[1]	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$88,082,827	$392,579,897
Industrial	$444,650	$1,852,709
Residential	$152,319,828	$287,241,242
Tax Exempt	$36,331,418	$80,527,110
Total	**$277,178,722**	**$762,200,958**

Total Damage by Category	Without-Project Dam Failure	With-Project Dam Failure
Total Commercial Content	$58,201,091	$237,605,344
Total Commercial Structure	$29,881,735	$154,974,554
Total Industrial Content	$223,764	$925,584
Total Industrial Structural	$220,886	$927,125
Total Residential Content	$55,335,268	$101,937,219
Total Residential Structural	$96,984,560	$185,304,023
Total Tax Exempt Content	$13,260,606	$28,527,980
Total Tax Exempt Structural	$23,070,813	$51,999,130
Total	**$277,178,722**	**$762,200,958**

Total Damage by City/Town°	Without-Project Dam Failure	With-Project Dam Failure
Corte Madera	$3,620,504	$10,935,971
Fairfax	$0	$0
Greenbrae	$4,316,252	$24,142,096
Kentfield	$166,823,344	$456,355,765
Larkspur	$26,991,110	$99,803,492
Ross	$73,094,787	$166,436,853
San Anselmo	$2,332,726	$4,431,067
Total	**$277,178,722**	**$762,105,243**

Total Inundated Parcels by City/Town°	Without-Project Dam Failure	With-Project Dam Failure
Corte Madera	18	34
Fairfax	0	0
Greenbrae	38	103
Kentfield	308	364
Larkspur	228	330
Ross	257	291
San Anselmo	31	31
Total	**880**	**1153**

By City/Town

Total Damage by Category for Corte Madera	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$3,138,482	$9,699,870
Industrial	$0	$337
Residential	$468,419	$1,153,858
Tax Exempt	$13,603	$81,906
Subtotal	**$3,620,504**	**$10,935,971**

Total Damage by Category for Fairfax	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$0	$0
Industrial	$0	$0
Residential	$0	$0
Tax Exempt	$0	$0
Subtotal	**$0**	**$0**

Total Damage by Category for Greenbrae	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$3,598,021	$19,462,846
Industrial	$444,650	$1,852,372
Residential	$273,582	$2,505,835
Tax Exempt	$0	$321,042
Subtotal	**$4,316,252**	**$24,142,096**

Total Damage by Category for Kentfield	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$56,825,754	$250,877,834
Industrial	$0	$0
Residential	$81,276,358	$141,095,490
Tax Exempt	$28,721,232	$64,382,441
Subtotal	**$166,823,344**	**$456,355,765**

Total Damage by Category for Larkspur	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$5,920,952	$45,864,997
Industrial	$0	$0
Residential	$20,542,273	$52,166,328
Tax Exempt	$527,884	$1,772,167
Subtotal	**$26,991,110**	**$99,803,492**

Total Damage by Category for Ross	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$18,583,605	$66,652,093
Industrial	$0	$0
Residential	$48,210,318	$88,191,394
Tax Exempt	$6,300,864	$11,593,366
Subtotal	**$73,094,787**	**$166,436,853**

Total Damage by Category for San Anselmo	Without-Project Dam Failure	With-Project Dam Failure
Commercial	$16,013	$22,257
Industrial	$0	$0
Residential	$1,548,878	$2,032,621
Tax Exempt	$767,835	$2,376,189
Subtotal	**$2,332,726**	**$4,431,067**

Notes:

* All damage estimates based on $200/sq. ft. of building footprint.
[1] Categories summarized from tax records.
° City/Town as designated in tax records.

Figure 1
Phoenix Lake Dam Failure Inundation Extent (Without Project)
Existing Dam Failure Inundation Extent Provided by MarinMap.org,
from State of Califonria (1974)
Image NAIP (2009)

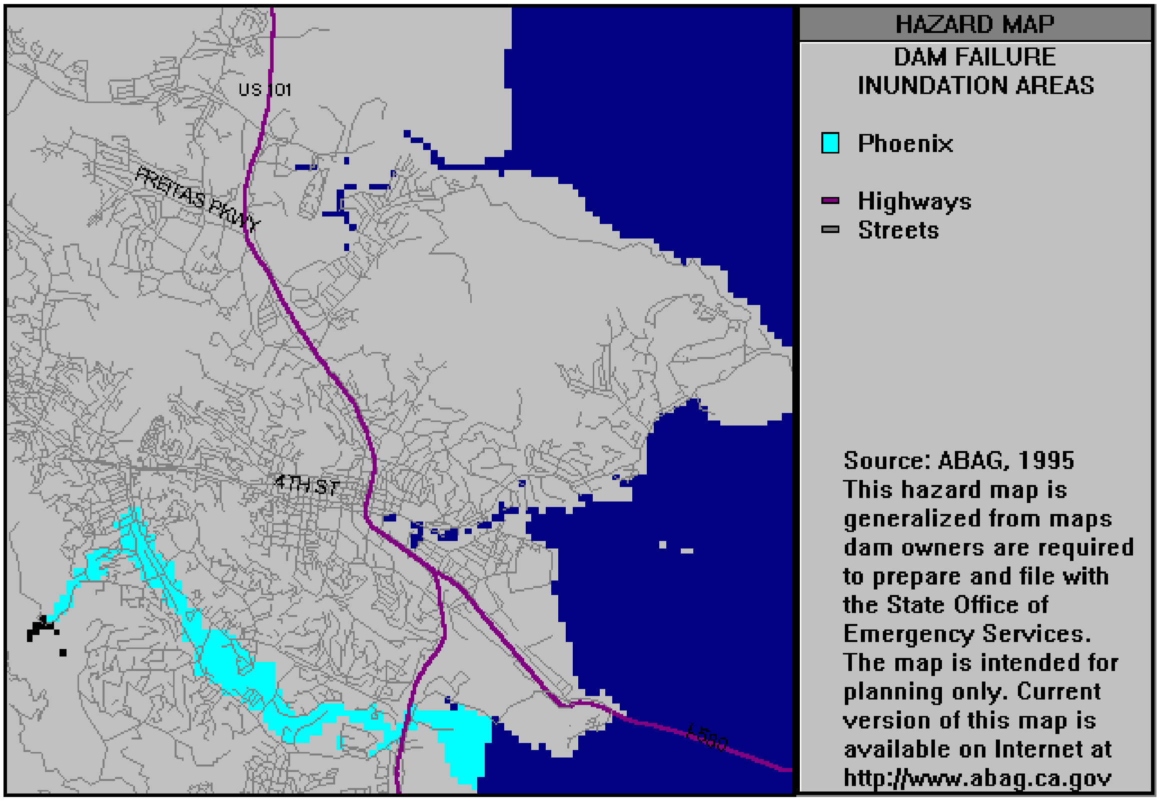
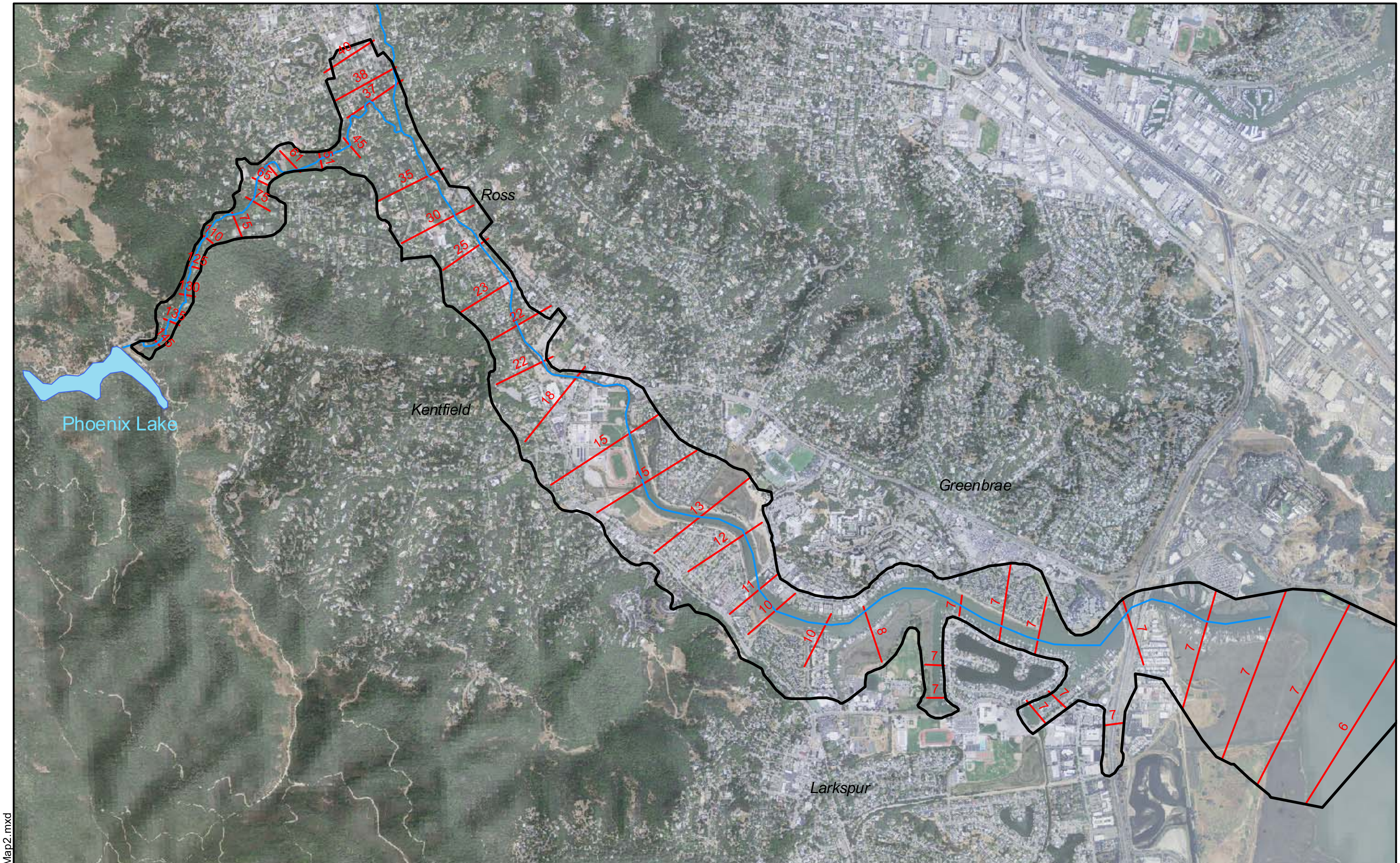


Figure 2 Phoenix Lake Dam Failure Inundation Areas (Source: ABAG, 1995)



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Existing Dam Failure Inundation Extent

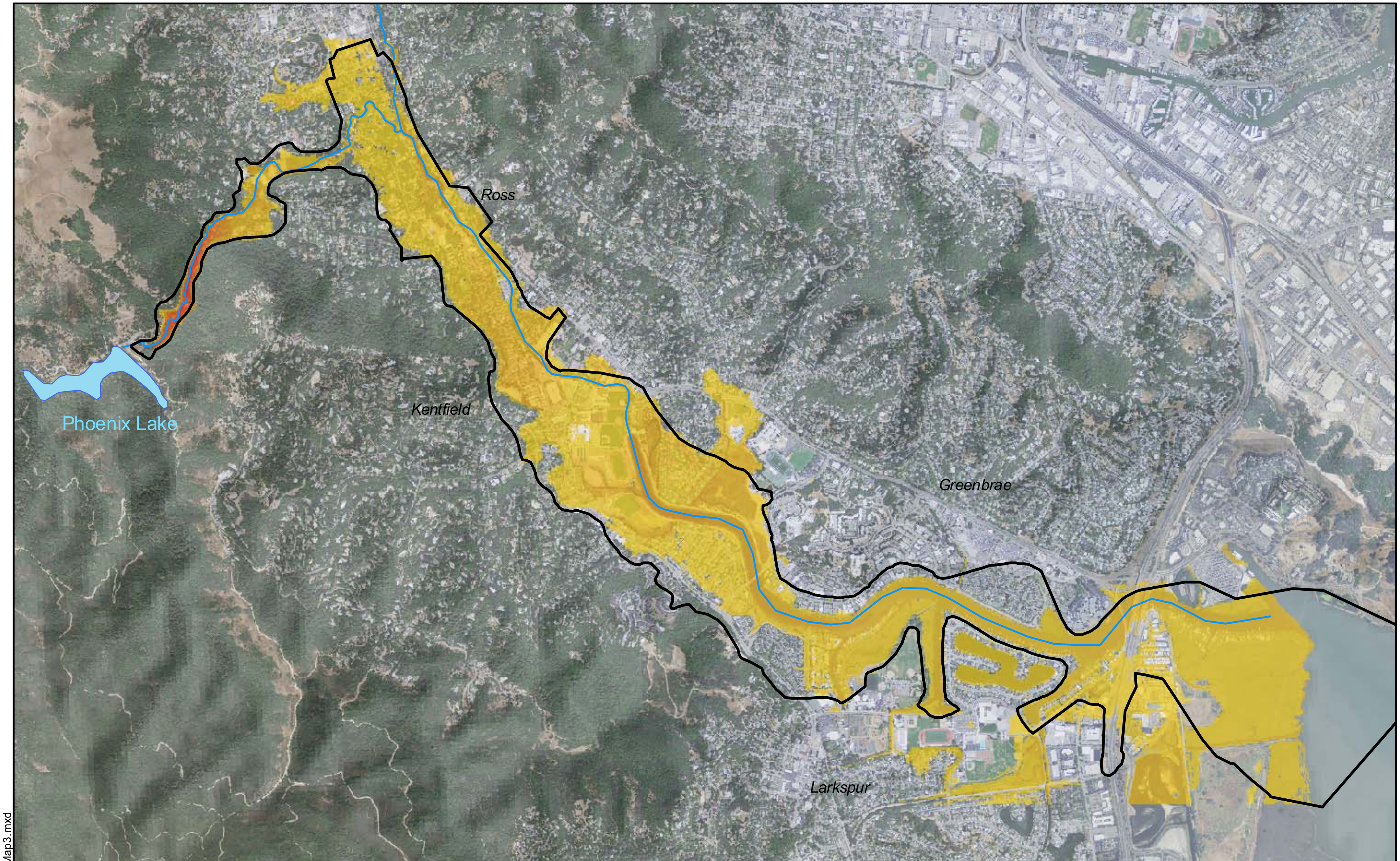
Cross-Section (WSE in ft)

Figure 3
Existing Phoenix Lake Dam Failure Inundation Extent (With Project) and Cross Section at Selected Locations

Existing Dam Failure Inundation Extent provided by MarinMap.org, from State of California (1974)
Background 2009 NAIP and 2m Digital Elevation Model

N

0 0.25 0.5 Miles



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STETSON ENGINEERS INC.

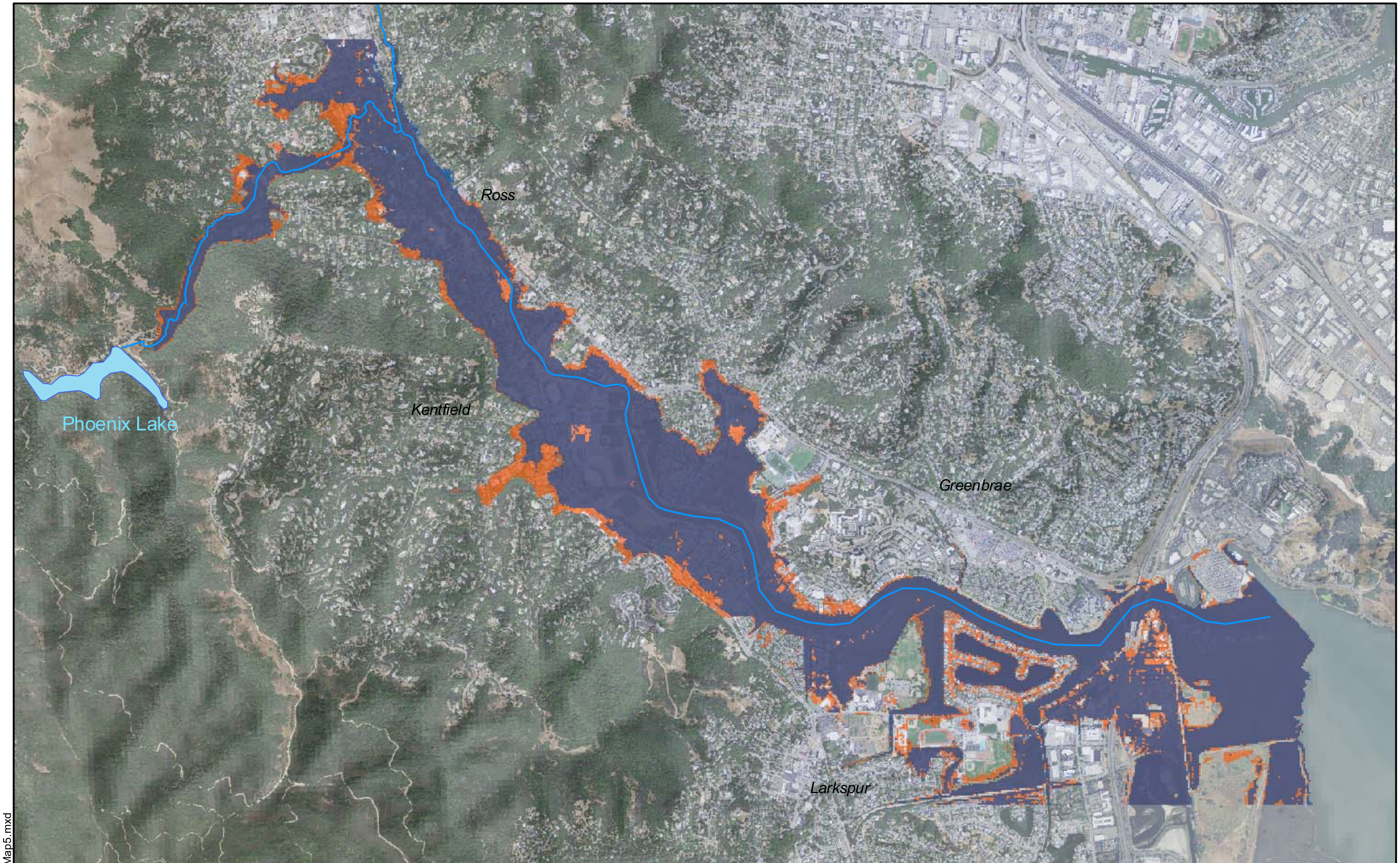
Modified Dam Failure Inundation Extent

Existing Dam Failure Inundation Extent

Figure 4
Modified Phoenix Lake Dam Failure Inundation Extent (Without Project)
Existing Dam Failure Inundation Extent provided by MarinMap.org,
from State of California (1974)
Image NAIP (2009)

N

0 0.25 0.5 Miles



Modified Dam Failure Inundation Extent Withour Project Conditions

Modified Dam Failure Inundation Extent With Project Conditions

Figure 5
Modified Phoenix Lake Dam Failure Inundation Extent Without Project vs. With Project Conditions

Background 2009 NAIP

0 0.25 0.5 Miles

N

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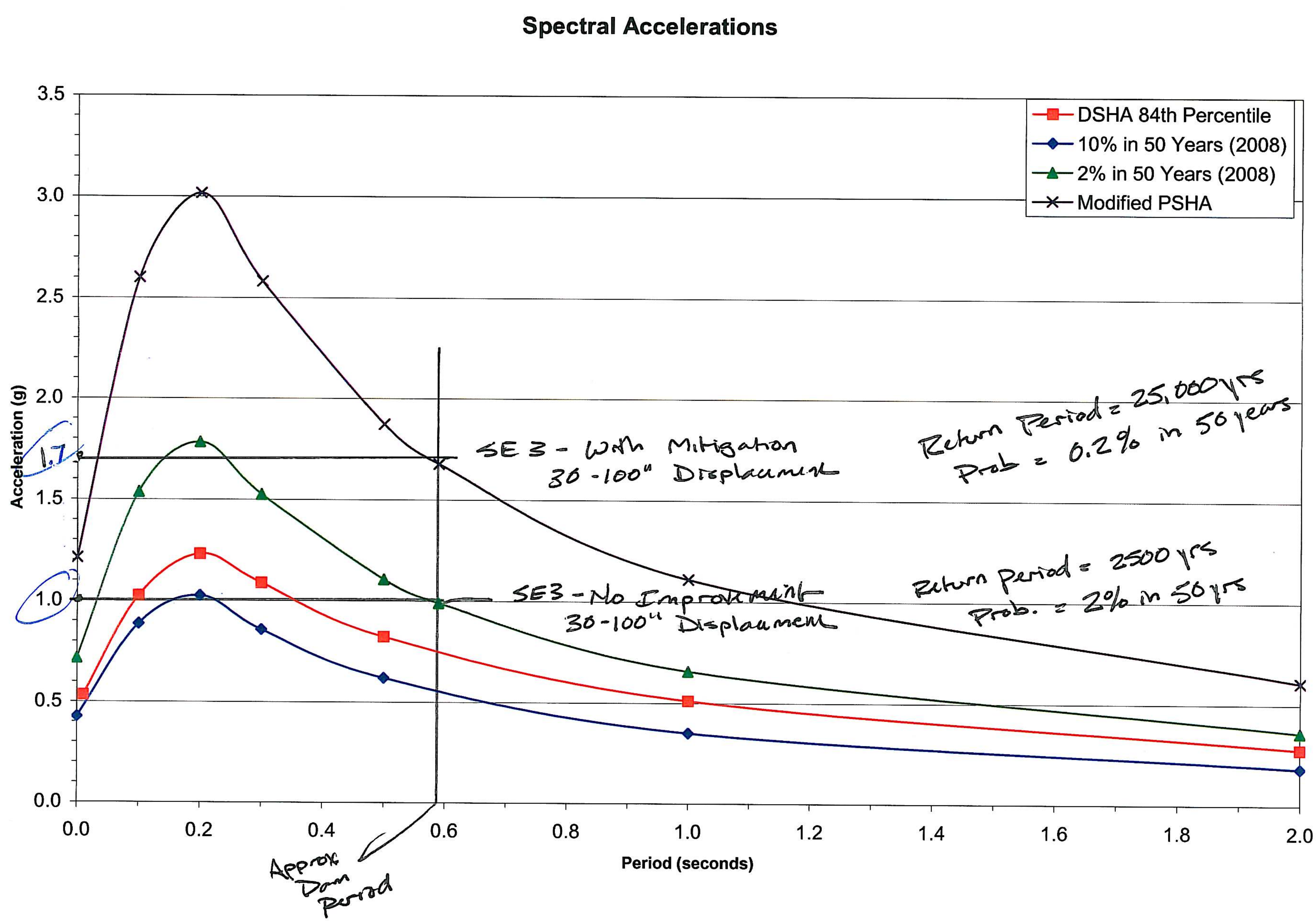
Appendix 3 to Attachment 7

Miller Pacific's Analysis Results of the Increased Ability of Phoenix Lake Dam to Resist Seismic Motions after Seismic Improvements



Spectral Accelerations
DSHA 84th Percentile
10% in 50 Years (2008)
2% in 50 Years (2008)
Modified PSHA
Acceleration (g)
3.5
3.0
2.5
2.0
1.7
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Period (seconds)
SE3 - With Mitigation
30-100" Displacement
Return Period = 25,000 yrs
Prob = 0.2% in 50 years
SE3 - No Improvement
30-100" Displacement
Return Period = 2500 yrs
Prob. = 2% in 50 yrs
Approx Dam Period

Simplified Procedure for Estimating Earthquake Induced Deviatoric Slope Displacements
by Jonathan D. Bray and Thaleia Travasarou
Journal of Geotechnical and Geonvironmental Engineering, ASCE, V. 133(4), pp. 381-392, April 2007

SEE NOTES BELOW FOR GUIDANCE IN THE USE OF SPREADSHEET

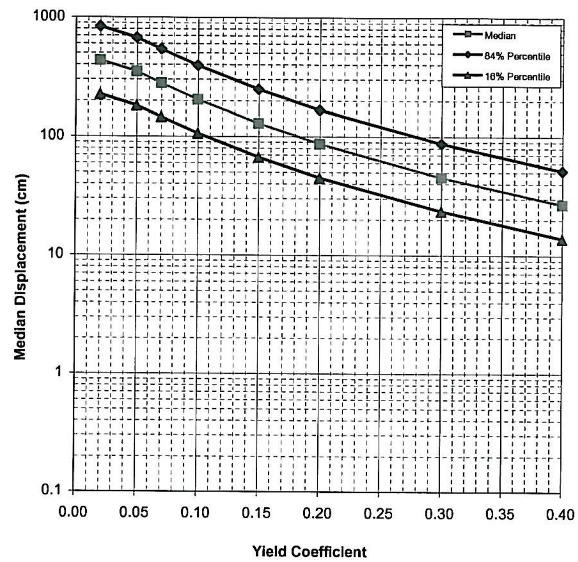
Input Parameters		
Yield Coefficient (ky)	0.15	
Slope Height (feet or meters)	90	Based on pseudostatic analysis
Vs (fps or mps)	600	1D: Ts=4H/Vs
1D or 2D Analyses	2D	2D: Ts=2.6H/Vs
Initial Fundamental Period (Ts)	0.39 seconds	
Degraded Period (1.5Ts)	0.59 seconds	
Moment Magnitude (Mw)	7.9	
Spectral Acceleration (Sa(1.5Ts))	1.675 g	

Additional Input Parameters	
Probability of Exceedance #1 (P1)	84 %
Probability of Exceedance #2 (P2)	50 %
Probability of Exceedance #3 (P3)	16 %
Displacement Threshold (d_threshold)	5 cm

Intermediate Calculated Parameters		
Non-Zero Seismic Displacement Est (D)	132.03 cm	eq. (5) or (6)
Standard Deviation of Non-Zero Seismic D	0.66	

Results			
Probability of Negligible Displ. (P(D=0))	0.000		eq. (3)
D1	68.49 cm	26.96 in	eq. (7)
D2	132.03 cm	51.98 in	eq. (7)
D3	254.52 cm	100.20 in	eq. (7)
P(D>d_threshold)	1.000		eq. (7)

ky	P(D="0")	D (cm)	Dmedian (cm)	D1 (cm)	D3 (cm)
0.020	0.00	433.1	433.1	835.0	224.7
0.05	0.00	348.3	348.3	671.5	180.7
0.07	0.00	279.4	279.4	538.7	145.0
0.1	0.00	203.8	203.8	392.8	105.7
0.15	0.00	128.4	128.4	247.4	66.6
0.2	0.00	86.5	86.5	166.8	44.9
0.3	0.00	45.2	45.2	87.2	23.5
0.4	0.00	26.7	26.7	51.4	13.8



Notes

1. Values highlighted in blue are input parameters
2. Probability of Exceedance is the desired probability of exceeding a particular displacement value.
3. Displacements D1, D2, and D3 correspond to P1, P2, and P3, respectively.
   (e.g., the probability of exceeding displacement D1 is P1)
4. Calculated seismic displacements are due to deviatoric deformation only (add in volumetrically induced movement).
5. ky may range between 0.01 and 0.5, Ts between 0 and 2 s, Sa between 0.002 and 2.7 g, M between 4.5 and 9
6. Rigid slope is assumed for Ts < 0.05 s
7. When a value for D is not calculated, D is < 1cm
8. ky may be estimated using the simplified equations shown below.
9. Examples of how Ts is estimated are shown below.
10. Vs = weighted avg. shear wave velocity for the sliding mass, e.g., for 2 layers, Vs = [(h1)(Vs1) + (h2)(Vs2)]/(h1 + h2)

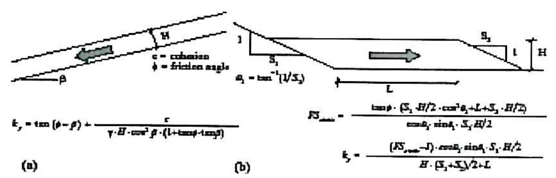


Fig. 14.1. Simplified estimates of the yield coefficient: (a) shallow sliding and (b) deep sliding

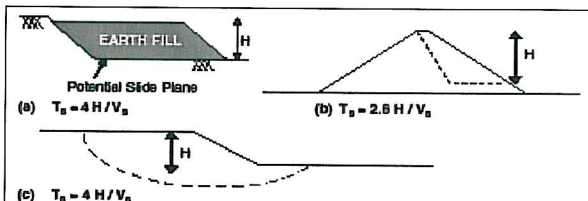


Fig. 14.4. Estimating the initial fundamental period of potential sliding blocks

Figures from Bray, J.D. (2007) "Chapter 14: Simplified Seismic Slope Displacement Procedures," Earthquake Geotechnical Engineering, 4th Inter. Conf. on Earthquake Geotechnical Engineering - Invited Lectures, in Geotechnical, Geological, and Earthquake Engineering Series, Vol. 6, Pitilakis, Kyriazis D., Ed., Springer, Vol. 6, pp. 327-353.

Conterminous 48 States
2002 Data
Hazard Curve for PGA
Latitude = 37.955458
Longitude = -122.575651
Data are based on a 0.05 deg grid spacing
Frequency of Exceedance values less than
1E-4 should be used with caution.

Ground Motion (g)	Frequency of Exceedance (per year)
0.005	4.333E-01
0.007	3.853E-01
0.010	3.2799E-01
0.014	2.6501E-01
0.019	2.022E-01
0.027	1.4669E-01
0.038	1.0241E-01
0.053	6.9102E-02
0.074	4.5798E-02
0.103	3.0503E-02
0.145	2.0128E-02
0.203	1.2783E-02
0.284	7.3382E-03
0.397	3.6647E-03
0.556	1.4692E-03
0.778	4.2475E-04
1.090	8.0854E-05
1.520	7.7693E-06
2.130	1.1023E-07

Ground Motion (g)	Freq. of Exceed. (per year)	Return Pd. (years)	P.E. %	Exp. Time (years)
1.2110	3.8517E-05	25962.65	0.19	50.0

Frequency of Exceedance values less than
1E-4 should be used with caution.

DSHA 84th Percentile		10% in 50 Years (2002)		10% in 50 Years (2008)		2% in 50 Years (2002)		2% in 50 Years (2008)			
T, sec	Sa, g's	T, sec	Sa, g's	T, sec	Sa, g's	T, sec	Sa, g's	T, sec	Sa, g's	T, sec	Sa, g's
0.01	0.53	0.00	0.49	0.00	0.42	0.00	0.78	0.00	0.72	0.00	1.211
0.10	1.02	0.10	0.88	0.10	0.89	0.10	1.40	0.10	1.54	0.10	2.599
0.20	1.23	0.20	1.12	0.20	1.02	0.20	1.83	0.20	1.78	0.20	3.016
0.30	1.09	0.30	1.07	0.30	0.86	0.30	1.77	0.30	1.52	0.30	2.580
0.50	0.82	0.50	0.85	0.50	0.62	0.50	1.48	0.50	1.11	0.50	1.872
1.00	0.51	1.00	0.53	1.00	0.35	1.00	0.95	0.59	0.99	0.59	1.675
2.00	0.28	2.00	0.27	2.00	0.18	2.00	0.51	1.00	0.66	1.00	1.110
								2.00	0.36	2.00	0.607